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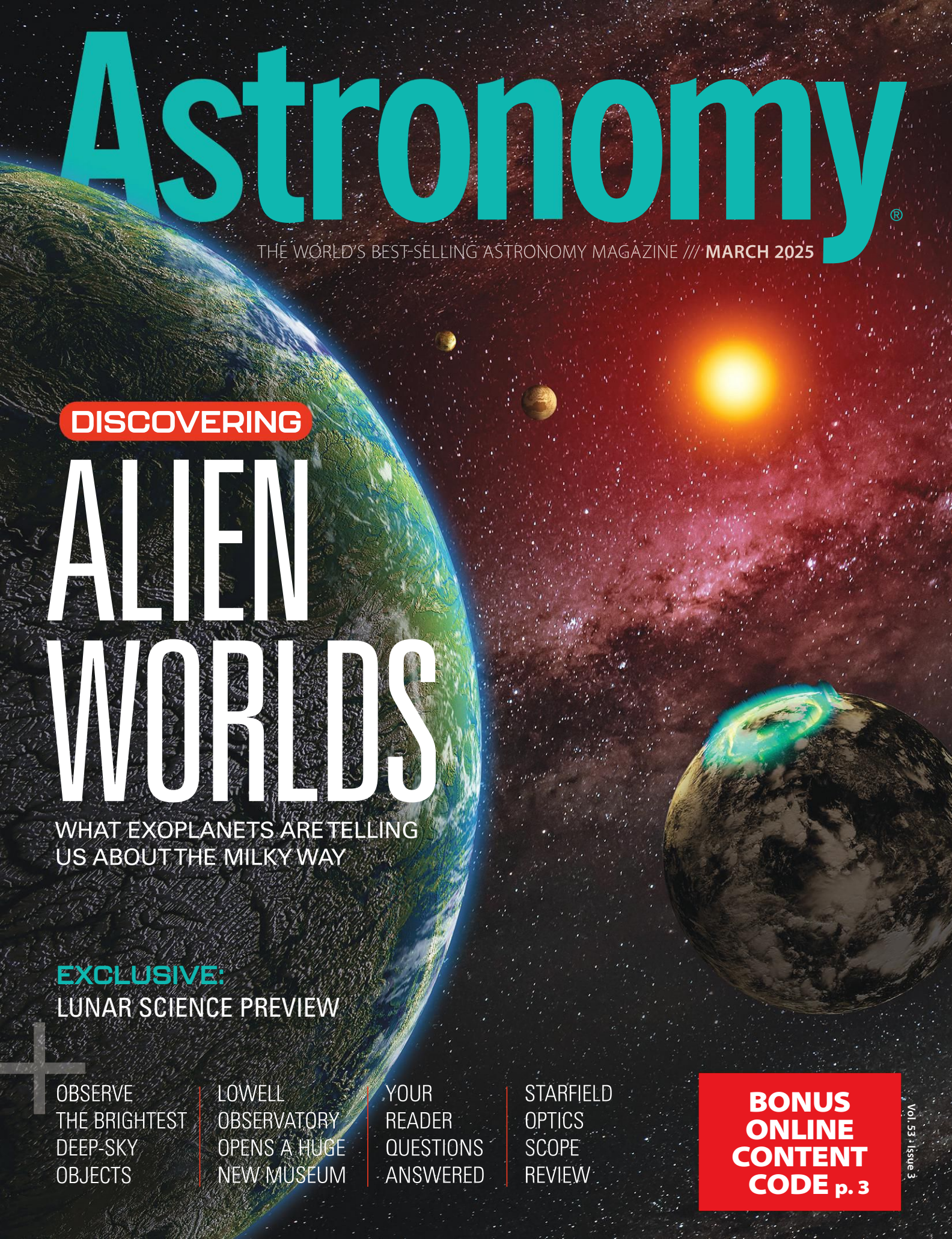

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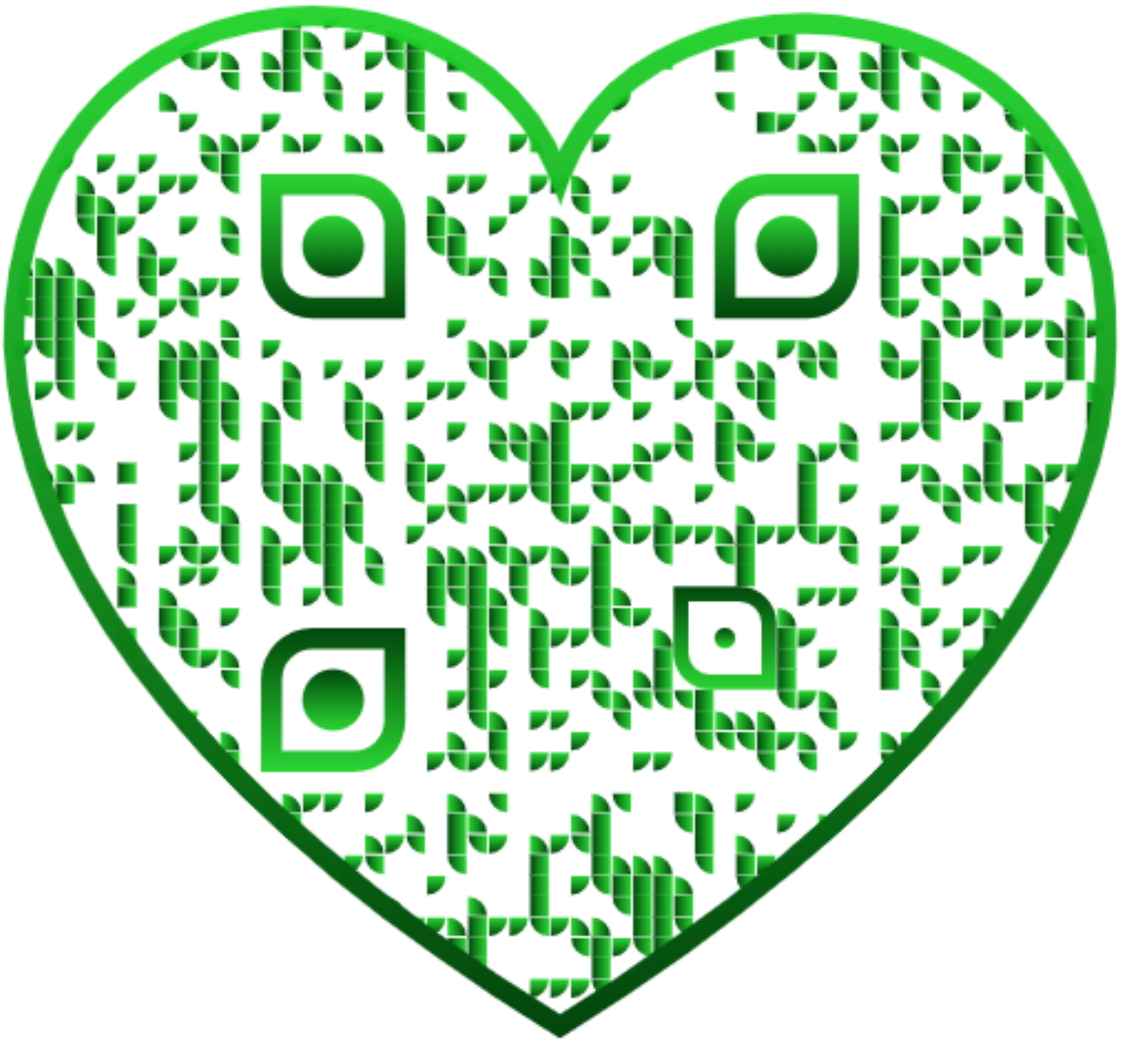

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The super-Earth in this illustration is in a planetary system whose central star is a red dwarf. Super-Earths are larger than our planet but smaller than Neptune.

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The eclipse of a lifetime

The 2027 eclipse will pass over the Temple of Luxor, seen here at night. NUVISTA/DREAMSTIME.COM

Astronomers love eclipses. For that matter, pretty much everyone does — it's amazing to see a person experience their first total solar eclipse, astonished that the timing of the alignment of celestial bodies is so precisely known. The countdown ensues, and magic seems to happen when the diamond ring flashes and darkness descends. A surreal atmosphere takes over. People become emotional, some even brought to tears.

Arguably the biggest solar eclipse for the rest of our lives will happen Aug. 2, 2027. It will be a long eclipse, and will offer the opportunity for viewing from one of the most amazing places on Earth. And the prospects for a photometrically-clear sky will be about as good as they possibly can be.

What am I talking about? Egypt. I had the pleasure of touring Egypt in 2004 at the time of the transit of Venus, and lemme tell you, there is no other place on the planet like Egypt. Granted, in another life I probably would be an archaeologist, but the scale and preservation of the antiquities is mind-blowing.

In 2027, the eclipse will pass over the great Temple of Luxor, and totality will last 6 minutes 23 seconds — nearly as long as a solar eclipse can last. Across the Nile will be the Valley of the Kings, including Tutankhamun's famous tomb, and the Valley of the Queens, and tours will visit a battery of amazing sites.

Our tour partner, Eclipse Traveler, will lead the way, and I will happily be joining the Egyptian festivities. Eclipse Traveler will be operating three tours, and sites include the Pyramids and Cairo, Alexandria, Petra, the Dead Sea, Idfū, Kawm Umbū, and a Nile cruise. Check out the website at eclipsetraveler.com for complete descriptions of all the possibilities.

You will not want to miss this eclipse. This is the big one. I look forward to seeing you there!

Yours truly,

David J. Eicher
Editor

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FIRECROWN

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Just the right combination of water droplets, sunlight, reflection, and refraction created this rainbow near Flateyri, Iceland. SINDRE SKREDE/FLICKR/CC BY 2.0

We welcome your comments via email to **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Colorful phenomenon

In Raymond Shubinski's recent article on rainbows ("How to Read Rainbows," November 2024), it was stated that rainbows are "in the mind of the beholder." If rainbows are only seen within our minds, how is it possible to photograph them? **—David Weitzel,** St. Helens, OR

Contributing Editor Raymond Shubinski responds: You pose an interesting question. In my article, I make the point that rainbows are not physical and require water droplets, sunlight, reflection, and refraction to be produced. This allows us to not only see a rainbow but photograph it. We can't think of a rainbow as a "thing," but only as a phenomenon. You may see your own personal rainbow, but rainbows and our ability to separate light into millions of wavelengths of energy are not only tangible, but amazing.

Eclipsed the year

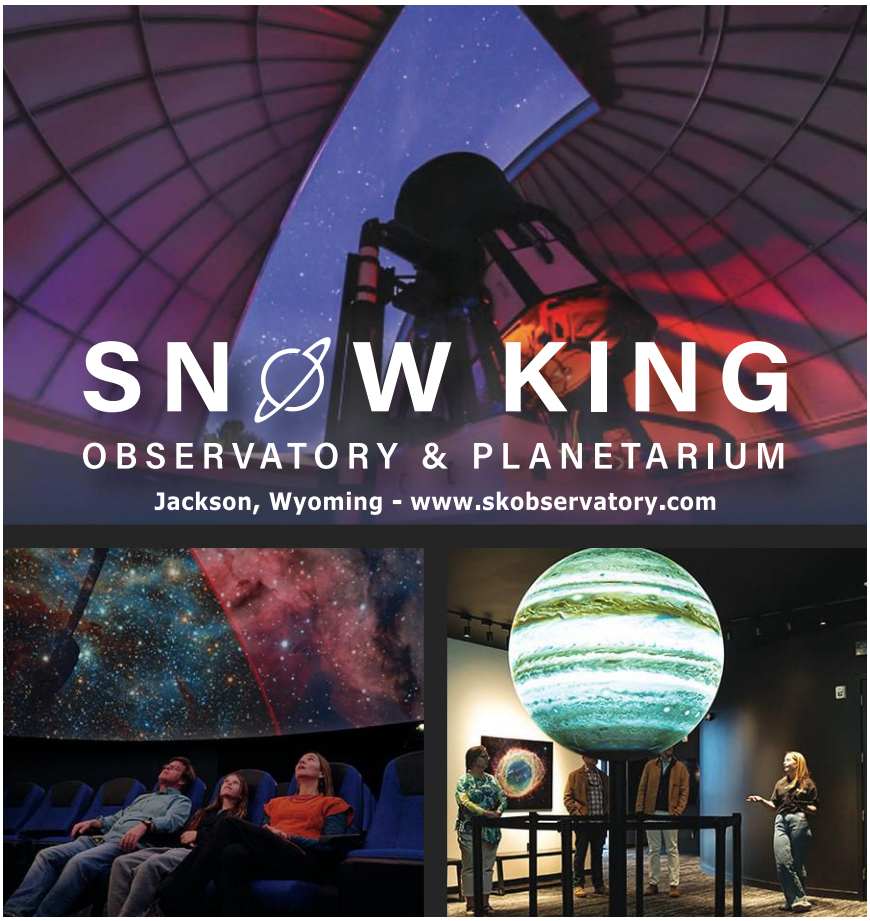
We asked our followers on social media, "What's your favorite astronomical phenomenon from this year?" The response was overwhelmingly in favor of the 2024 North American Eclipse in April, while others also enjoyed the aurora borealis. Here are some of your responses:

"Hard to beat seeing the total eclipse from northern Vermont!"**—Maggie Fiore**

"Driving from Spokane, Washington, to Bedford, Indiana, for the April eclipse and northern lights in the lower 48 twice in five months, May and October." **—Joe Bruce**

"Every cosmic phenomenon draws our attention to something new and mysterious that can move our minds." **—David Weitzel**

Errata: *The January issue incorrectly attributed the article "Artemis explained" to Mark Zastrow. Although Mark edited the article,* Astronomy *contributor Robert Reeves wrote it.*



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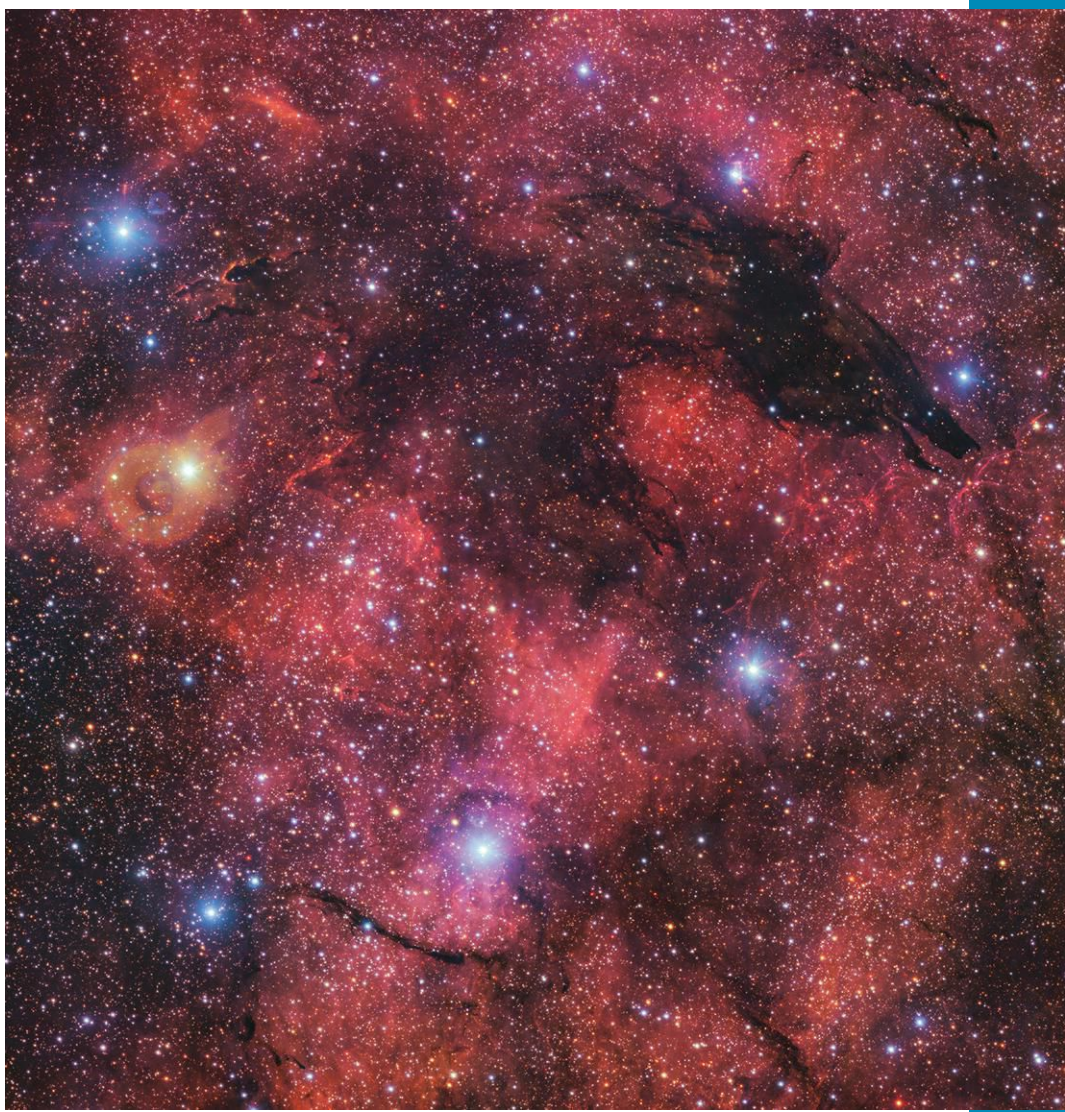
SNAPSHOT

A DARK WOLF

This shadowy figure stalks the Scorpion through the dense dust lanes of the Milky Way.

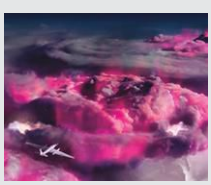


Inside the unassumingly named nebula Gum 55 lies a rift of dust grains that absorb visible light, creating a swath of darkness against the glowing gas. Fittingly named for its shape, the Dark Wolf Nebula is no mere puppy — it spans an area some four times the size of the Full Moon. Gum 55 is even bigger, a huge stellar nursery birthing fiercely-burning stars whose radiation pushes away the material that formed them, creating shells and pillars of denser material. These complex layers create beautiful and evocative shapes, including the piles of dark dust that comprise the Dark Wolf Nebula. The Dark Wolf and Gum 55 reside in Scorpius near the heart of the Milky Way, some 5,300 light-years distant. The European Southern Observatory's (ESO) VLT Survey Telescope at Paranal, Chile, resolved this image, which was released Oct. 31.

— KOREY HAYNES

ESO/VPHAS+ TEAM. BOTTOM FROM LEFT: NASA/ALOFT TEAM; NASA/JPL-CALTECH; NASA/CSA/ESA. M. XIAO & P. A. OESCH (UNIVERSITY OF GENEVA), G. BRAMMER (NIELS BOHR INSTITUTE), DAWN JWST ARCHIVE

HOT BYTES

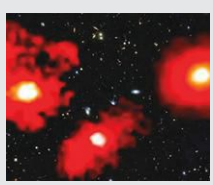


GAMMA-RAY GLOW

Thunderclouds produce gamma rays in short bursts and longer-lasting glows. Airborne observations have now also discovered intermediate-length gamma-ray flickers; understanding them could help predict lightning strikes.

ALTERED STATE

Temporary changes brought on by a blast of solar wind could explain the strange magnetic field observed at Uranus by Voyager 2 in 1986.

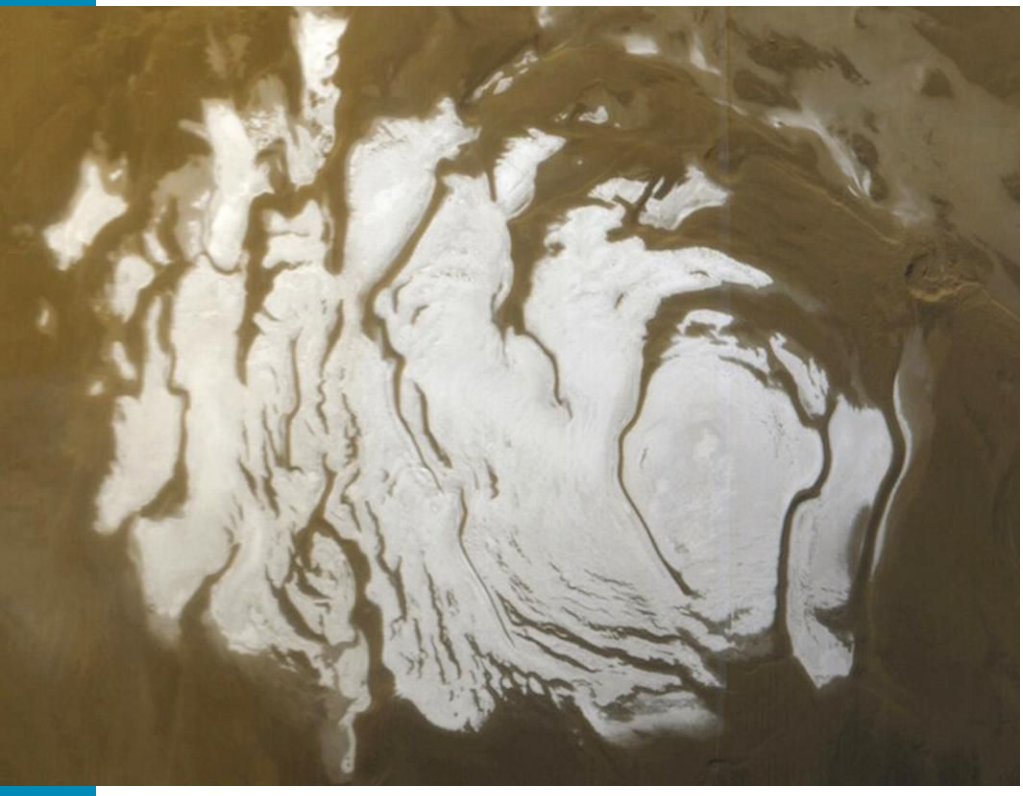


RED MONSTERS

JWST spotted three dusty, Milky Way-sized galaxies within 1 billion years of the Big Bang. Their size at this time indicates that early stars may have formed faster than previously thought.

CARBON DIOXIDE GLACIERS GAVE MARS LIQUID WATER

Insulation from carbon dioxide ice above the polar caps could explain many of the Red Planet's ancient river features.



CARBON CAP. Mars' south polar ice cap, imaged here during summer, has a diameter of some 260 miles (420 km). Although the amount of carbon dioxide ice and frost waxes and wanes with the seasons, the underlying water ice remains, and may have been the source of many of Mars' river features. NASA/JPL-CALTECH/MALIN SPACE SCIENCE SYSTEMS

Mars hosts numerous geologic features formed by flowing water: valleys; canyons; fanlike washes of sand and rock; and long, winding gravel ridges called eskers. Yet for decades, scientists have been unable to determine how and when Mars melted the large amounts of liquid water necessary to create them.

Peter Buhler, a research scientist at the Planetary Science Institute, has modeled a solution: that carbon dioxide condensed out of Mars' atmosphere in a glacier nearly 0.4 mile (0.6 kilometer) high, smothering even-larger water-ice glaciers and melting them out into rivers thousands of miles long. He published his research Nov. 1 in the *Journal of Geophysical Research: Planets*.

GEOLOGIC SEASONS

Buhler's model attempts to pinpoint the mechanism that warmed Mars sufficiently to melt enough water to form the many large and varied river features that cross its surface to this day. "The current best hypothesis is that there was some unspecified global warming event," Buhler said in a press release, "but that was an unsatisfying answer to me, because we don't know what would have caused that warming."

Buhler's model relies on a cycle scientists believe is still happening today. Currently, Mars' tilt is 25°, similar to Earth's 23°. But over hundreds of thousands or millions of years, Mars wobbles to a far greater extent than Earth: Studies show it may swing all the way from upright (0°) to 80°, with its poles nearly pointed at the Sun.

This wobble drives a carbon dioxide cycle, like seasonal changes but on a geologic time scale. When the equatorial regolith is baked by the Sun, carbon dioxide evaporates into the atmosphere, where it cools and condenses as ice near the poles, on top of the water-ice caps there.

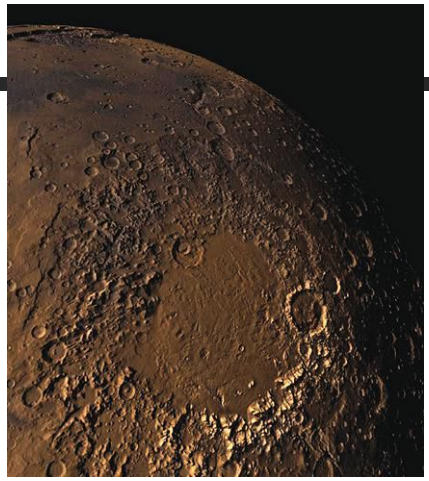
When the poles are more directly warmed by the Sun, the carbon dioxide ice there sublimates back into the atmosphere. The regolith near the equator then reabsorbs the carbon dioxide until the next cycle. Today, much of Mars' carbon dioxide is stored in the regolith, sheathing each grain of rock in a layer just one molecule thick.

GLACIERS MELTING GLACIERS

Buhler looked at how this cycle would have operated some 3.6 billion years ago. At that time, the planet had a thicker atmosphere containing even more carbon dioxide — and it's also when scientists think many of Mars' river features appeared.

He found that warming the equatorial regions causes carbon dioxide to condense into a sheet 0.4 mile (0.6 km) thick at the poles, on top of a water-ice cap 2.5 miles (4 km) thick — about the same as the current martian south pole ice cap.

The carbon dioxide put pressure on the water-ice cap and also insulated it, trapping heat from below and melting the water ice underneath. Once the ground below was saturated, the excess water escaped in rivers that stretched thousands of miles, which filled and



ANCIENT HISTORY. Mars' Argyre Basin is an ancient impact feature roughly 1,100 miles (1,800 km) wide. Scientists have identified several major channels through which water once flowed into or out of the area. MOLA SCIENCE TEAM AND G. SHIRAH, NASA GSFC SCIENTIFIC VISUALIZATION STUDIO

eventually overflowed a feature called the Argyre Basin (roughly the size of the Mediterranean Sea), and finally washed out some 5,000 miles (8,000 km) away. Buhler estimates this process repeated several times over about 100 million years, forming the varied river terrain seen across Mars' surface today.

The model provides a new explanation using cycles still present on Mars today, and "demonstrates that large amounts of water can mobilize in a cold climate without invoking the fraught paradigm of late-stage climatic warming," he said. – K.H.

EATING CHAMPION. Black hole LID-568 is gobbling up matter at a rate 40 times greater than the theoretical limit, as seen in this artist's concept. NOIRLAB/NSF/AURA/J. DA SILVA/M. ZAMANI

Black hole eats faster than allowed

Astronomers have long puzzled over how the supermassive black holes residing in the center of galaxies form. Now, researchers may have found the biggest clue yet to how these monstrous objects — weighing millions to billions of solar masses — came to exist.

An international team used the James Webb Space Telescope's (JWST) high infrared sensitivity to investigate a group of galaxies previously studied by the Chandra X-ray Observatory. In that data, they found a supermassive black hole called LID-568 that was, for its size, suspiciously strong in X-ray emission. Its host galaxy exists a mere 1.5 billion years after the Big Bang, when galaxies were just reaching maturity on the cosmic scene.

The JWST observations revealed the black hole's intense outflows of gas and allowed the team to calculate their speed and size. Their results indicate that LID-568 consumes matter more than 40 times faster than what the theoretical limit — the so-called Eddington limit — permits. The discovery also "suggests that a significant portion of mass growth can occur during a single episode of rapid feeding," said Hyewon Suh of the International Gemini Observatory in a statement. Suh was first author of a study detailing the work, published Nov. 4 in *Nature Astronomy*.

Modern telescopes have consistently discovered black holes in the early universe that seem to have grown faster than physics says is possible. LID-568 may help resolve this situation, as it is the first direct evidence of a black hole experiencing super-Eddington accretion.

Perhaps, in a black hole's case, rules like the Eddington limit are made to be broken. – DANIELA MATA

QUICK TAKES

DARK MATTER SEARCH

A supernova in the Milky Way could solve the mystery of dark matter, a UC Berkeley team calculates. In such an explosion, NASA's Fermi space telescope could detect axions — a proposed dark-matter particle — as they transform into high-energy gamma rays.

FARSIDE VOLCANISM

Early analysis of samples from China's Chang'e 6 — the first mission to retrieve rocks from the Moon's farside — found volcanic samples with an age of 2.8 billion years. The find indicates volcanism on the farside was surprisingly long-lived.

MAGNETAR ORIGINS

The enigmatic events known as fast radio bursts (FRBs) are more likely in massive star-forming galaxies, says a Nov. 6 *Nature* paper. This suggests that the intense magnetic fields of magnetars — thought to be the source of most FRBs — form when stars in dense environments collide, merge, and later go supernova.

EXTRAGALACTIC BROWN DWARFS

The James Webb Space Telescope has detected the first known brown dwarf candidates outside of the Milky Way Galaxy. The "failed stars" lie in the open cluster NGC 602 in the Small Magellanic Cloud, roughly 200,000 light-years from Earth.

STAY OF EXECUTION

The Chandra X-ray Observatory — once set to be effectively shuttered at the end of 2024 — has been given a reprieve. NASA will reevaluate the space telescope's future after Congress appropriates funds for 2025.

CROWDSOURCED SPACE WEATHER

Millions of smartphones can act as a global sensor network to monitor space weather, researchers report. The team aggregated data from phones with dual-frequency GPS chips, which are sensitive to changes in the density of electrons in the ionosphere. – MARK ZASTROW

Astronomers urge pause to Starlink launches

Citing environmental concerns, 120 astronomers and researchers implored the Federal Communications Commission (FCC) in an Oct. 24 letter to halt launches of internet satellites like SpaceX's Starlink.

The letter, which was organized by the Public Interest Research Group (PIRG), also urged FCC Space Bureau Chief Julie Kearney to investigate the potential negative environmental and health impacts of the vast projected increase in satellites being disposed of in the atmosphere.

The number of existing satellites has increased by a factor of 12 in the last five years, with SpaceX alone launching around 60 percent of them. And in 2022, the U.S. Government Accountability Office (GAO) predicted 58,000 satellites would be launched by the end of the decade.

SIGNAL BOOST. A SpaceX Falcon 9 rocket lifts off from Space Launch Complex 40 at Cape Canaveral Space Force Station in Florida Dec. 8, 2024, carrying 23 Starlink satellites to orbit. SPACEX

Under existing practices, to avoid the possibility of long-term defunct space junk, satellites in large megaconstellations are placed in a low orbit so that they naturally deorbit after five years. They must then be replaced by subsequent launches.

Such satellites have increased global internet access. But the letter argues that unfettered competition between multiple megaconstellations should not be placed above possible environmental harms.

The American Astronomical Society (AAS) sent a letter to policymakers detailing similar concerns Sept. 27.

Increasingly, researchers have flagged potential environmental impacts from satellite megaconstellations — not only in emissions from launches but also metals burning up in the atmosphere when satellites reenter. The AAS estimated that a 42,000-satellite constellation vaporized on a five-year cycle would deposit at least 8,000 tons of metals into the atmosphere annually. And a study published in June in *Geophysical Research Letters* projected that the continuous disposal of megaconstellation satellites in the atmosphere would release nearly 400 tons of aluminum oxide compounds annually into the upper atmosphere, which could significantly deplete the ozone layer.

Satellite megaconstellations have already been under scrutiny for the light pollution they produce, which can negatively impact astronomical observations and animal behavior.

The problem, says PIRG, lies in how the FCC categorizes satellites under the National Environmental Protection Act (NEPA). This legislation requires an assessment of any major federal action that significantly affects the environment. In issuing licenses for satellites, the FCC has exempted large constellations from review. The letter calls on the FCC to end its practice of categorical exclusions for satellites, noting that the GAO found that the FCC "doesn't have a documented reason" for doing so.

The FCC is planning to review its categorical exclusion policies and expects to develop revisions to its current NEPA rules with the Council on Environmental Quality, which governs these policies, by July 1, 2025. — SAMANTHA HILL

VEGA'S SMOOTH DISK IS A MYSTERY

VEGA AND ITS ORBITING DEBRIS disk have been photographed countless times, but recently the James Webb Space Telescope (JWST) and the Hubble Space Telescope combined to capture it with unprecedented clarity. The Hubble image (near right) highlights dust the size of smoke particles in Vega's 100-billion-mile-wide (160 billion kilometers) disk. At far right, JWST's infrared view shows sand-grain-sized dust; here, the outer dust ring is analogous to our solar system's Kuiper Belt and extends 7 billion to 15 billion miles (11 billion to 24 billion km) from the star. Beyond it, a warm dust halo extends to 23 billion miles (37 billion km) out. The black spot at center in both images blocks the light of the brilliant star, making the disk easier to see. Normally such disks are divided by gaps carved out by forming planets. And Vega's disk does display one faint gap, at about 60 astronomical units from the star. (One astronomical unit is the average Earth-Sun

REPORT DOCUMENTS ARECIBO'S COLLAPSE

RADIO SILENCE. The wreckage of Arecibo Observatory is pictured here after its 900-ton main platform fell onto the dish below on Dec. 1, 2020. MICHELLE NEGRON, NATIONAL SCIENCE FOUNDATION

PUERTO RICO'S ARECIBO OBSERVATORY was felled by the combination of a hurricane, a never-before-seen equipment failure, and an "alarming" lack of concern from engineers and inspectors who saw crucial cables slipping out of their sockets years before the famed radio telescope collapsed, says an authoritative post-mortem released Oct. 24 by the National Academies of Sciences, Engineering, and Medicine.

The telescope's main platform came crashing down Dec. 1, 2020, after two key cables holding it up failed earlier that year. Those cables were held in place inside sockets filled with zinc. After Category 4 Hurricane Maria battered the observatory in 2017, "[g]radually the zinc lost its hold on the cables and allowed several of them to pull out," the report says. The collapse is the first documented case of "zinc creep" in such sockets leading to a catastrophic failure in over a century of use, the report says.

"Absent Maria, the committee believes the telescope would still be standing today but might have eventually collapsed if its unique, accelerated zinc creep had not been addressed before it was decommissioned," the report says.

There were human failures, too, the report found: "The Arecibo Telescope gave fair warning post-Maria that it was in structural distress through increasing cable socket pullout." Inspections in 2018 and 2019 found that key cables had begun to slip out of their sockets by as much as 1.5 inches (3.8 centimeters) — which "should have raised the highest alarm level, requiring urgent action. The lack of documented concern from the contracted engineers about the … cable pullouts or the safety factors between Hurricane Maria in 2017 and the failure is alarming."

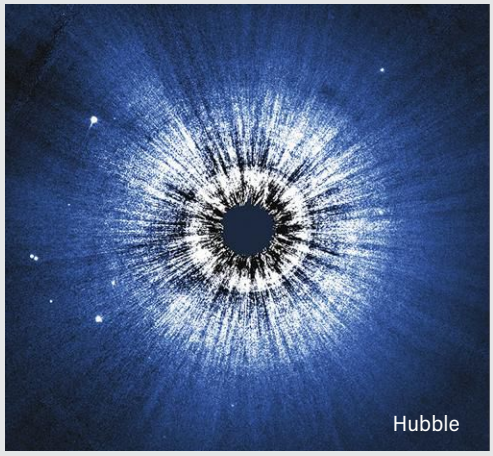
In the aftermath of Hurricane Maria, bureaucratic hold-ups delayed funding for repairs to the telescope. But because inspectors had failed to identify the cable slippage as the most pressing issue, "none of the proposed repairs would have saved the Arecibo Telescope from collapse," the report concluded.

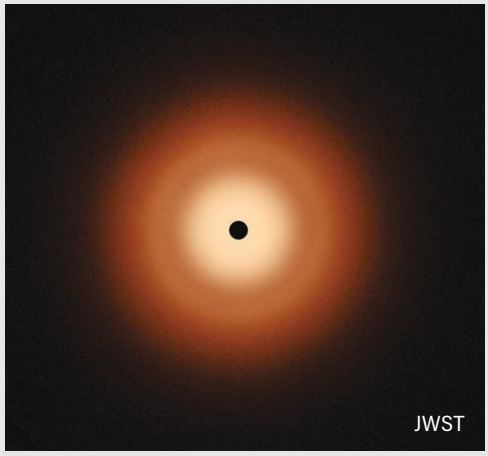
The committee says they do not know and cannot prove what caused Arecibo's extraordinary rate of zinc creep.

The only plausible hypothesis they could think of is that the electromagnetic radiation from Arecibo's radio transmitter — then the most powerful on Earth — may have accelerated the failure. When subjected to an electric field, it is possible for metals and ceramics to deform, a phenomenon called electroplasticity.

This transmitter distinguished Arecibo from many other radio telescopes that can only observe passively. It allowed the facility to act as a planetary radar and even send the occasional interstellar message, like the famed Arecibo Message. It would be ironic if this capability was what caused the telescope's downfall by weakening its sockets. – M.Z.

distance of 93 million miles [150 million km].) But astronomers expected to see more. The remarkably smooth disk devoid of clear signs of planet formation now presents a puzzle for researchers to work out. – D.M.





NASA, ESA, CSA, STScI, S. WOLFF (UNIVERSITY OF ARIZONA), K. SU (UNIVERSITY OF ARIZONA), A. GASPAR (UNIVERSITY OF ARIZONA)

Visual peculiarities of lunar eclipses

Expect to see the unexpected during this month's total lunar eclipse.

LEFT: A pink Moon was captured by Brian Cudnik of Houston during the Nov. 7, 2023, total lunar eclipse. BRIAN CUDNIK

RIGHT: The illusory irregular shape of Earth's shadow develops a mustache with Mare Frigoris during the Sept. 18, 2024, partial lunar eclipse, as seen over Maun, Botswana. STEPHEN O'MEARA

BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.

All lunar eclipses — whether penumbral, partial, or total — offer us thought-provoking views of Earth's shadow. Frequently, lunar eclipses offer up peculiar color effects, with the shadowed Moon appearing reddish due to the state of Earth's atmosphere. But the March 14, 2025, total lunar eclipse all but guarantees additional optical phenomena of a different kind, some of which could distort one's perception of reality, even if momentarily.

Let's start with the color effects. Take, for instance, the peculiar pink Moon that Brian Cudnik of Houston observed during the total lunar eclipse of Nov. 7/8, 2022. Cudnik captured the eclipse by holding his Samsung Galaxy up to the 41mm eyepiece of a Celestron 11 telescope. Of his image, he writes, "This … nicely approximates what I saw through the eyepiece — a pinkish tinge to the eclipse."

Cudnik noticed the coloring began around 15 minutes prior to totality and lasted until almost third umbral contact. However, through 20x80 binoculars and with unaided eyes, totality appeared more orange. Specific shades of pink can be made by mixing red/orange and white, so the apparent visual discrepancy between the telescopic view and the binocular/naked-eye view may simply be due to color mixing and image size. If you shrink Cudnik's telescopic image of the pink Moon by looking at it from a distance, the Moon suddenly becomes more orange.

If you shrink the image of the pink Moon, it suddenly becomes more orange.

But the Moon's morphing appearance isn't just limited to changes in color. Another reader, Joe Bauman of Salt Lake City, wrote to say that during the May 26, 2021, total lunar eclipse, he observed illusory lunar canals, a phenomenon that was enhanced by passing clouds over the eclipsed Moon.

Bauman's observation is reminiscent of a stunning visual effect visible during lunar eclipses. During the deep penumbral and umbral stages, the leading edge of Earth's shadow may not appear curved but highly irregular. Lunar shapes may appear magnificently large or oddly detached. Some are small and patchy, others long and thin. It's a visual illusion created by various optical effects as Earth's curved shadow interacts with dark mare features on the Moon.

While we know intellectually that Earth's shadow edge is curved, all manner of irregularities may appear only under certain conditions, such as the Moon entering the lunar disk at ingress, and depending on the intensity of the shadow (light or dark) and one's visual perception. For example, the Sept. 17/18, 2024, partial lunar eclipse offered astounding visual illusions and shapeshifting effects. First, as Earth's shadow entered the northern lunar limb, the tip of the curved edge bled into the long form of Mare Frigoris, causing the umbra to suddenly appear as if it had a mustache. The shadow then slipped into the northern reaches of Mare Imbrium, making the shadows appear like a maple leaf. Around that time, a pronounced reddening also appeared in Mare Imbrium. This may have been due to the color of Earth's shadow, which was expected to turn red.

Nevertheless, I found it curious. One would expect the reddish coloration of the Earth's shadow to be most pronounced over the bright lunar highlands. But the reddish-brown tone I saw was like an island of color in northern Mare Imbrium, appearing most prominent just south of the crater Plato. I suspect the reddish hue of Earth's shadow somehow enhanced the soft and subtle reddish tone of this late-stage iron-rich section of mare basalt — where China's Chang'e 5 lunar sampler mission landed.

After maximum eclipse (only 8 percent), the umbral shadow slipped eastward over Lacus Mortis and parts of Lacus Somniorum, creating more irregularities before exiting over the highlands east of Mare Frigoris, and making the last vestige of the umbral shadow appear like a tadpole with a long tail.

Now I'm interested to learn what you see during this month's total eclipse, when the umbral shadow will sweep in from the east and pass over all the lunar mare. As always, let me know what you see or don't see at sjomeara31@gmail.com.

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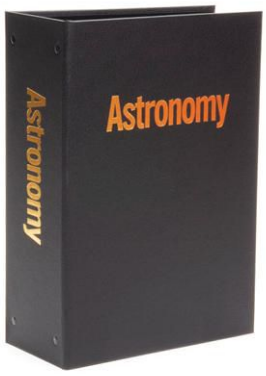

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Abstract

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30 YEARS OF exoplanets

Innovative techniques are enabling astronomers to reveal thousands of worlds beyond our solar system.

BY DONALD GOLDSMITH

IN OCTOBER 1995, after decades of serious effort, astronomers announced the first discovery of a planet orbiting a Sun-like star. Until then, the few planets known to exist beyond the solar system accompanied pulsars, the collapsed remnants of burnt-out stars, and had revealed themselves through glitches in the precise timing of the pulsars' radio emission. Because these strange cinders hardly resembled the Sun, the discovery in 1995 finally reassured astronomers that our solar system indeed has relatives — perhaps even near-twins — in the Milky Way.

However, the first exoplanet, and five more that followed in the first half of 1996, qualified only as distant cousins. Because the technique that revealed them could find only massive planets, these exoplanets had masses comparable to Jupiter's. But instead of circling their stars at separations comparable to the Jupiter-Sun distance, four of them had orbits far smaller than Mercury's, and none came close to the size of Jupiter's. Until then, using the solar system as a prototype, all models of how planets form had explained that small, rocky planets should develop close to their stars. Likewise, much larger, mostly gaseous planets would form farther out where they could amass great amounts of gas away from the star's heat.

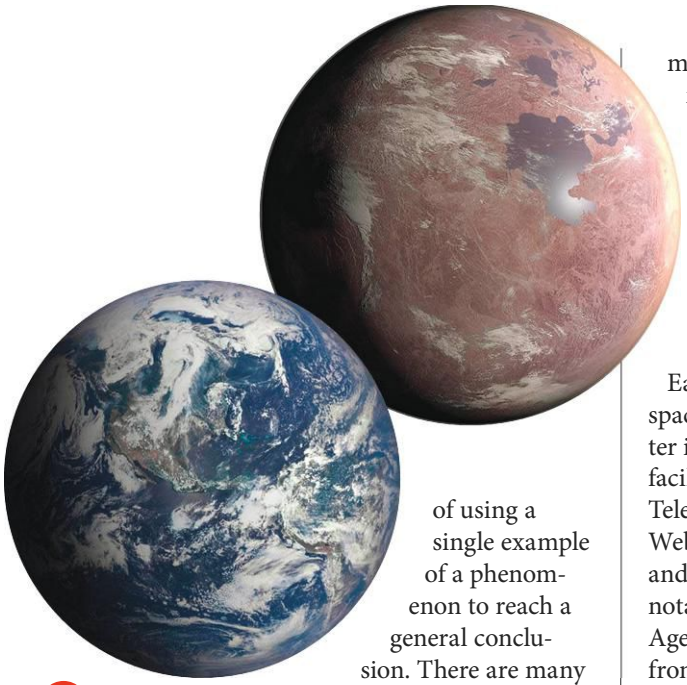
These first discoveries prompted theorists to spring into action. They produced models of gas giants that are born far from their stars, then migrate inward through gravitational interaction with the disk of material that formed the planets.

From the first discovery of planets beyond our Sun, the notion of our solar system as prototypical was wiped away. And the surprises have only continued.

A rich tapestry

Today, the first six exoplanets provide 0.1 percent of the entries in the catalogs maintained by NASA and the European Space Agency. Astronomers have found the great majority of these planets with just two different discovery methods, while a handful of other techniques have produced an additional minority. Their successes verify and emphasize an overarching result: Exoplanets exist in large numbers and display an amazing variety in their diameters, masses, densities, and compositions, as well as in the sizes and eccentricities of their orbits. This wealth of exoplanet riches underscores the danger, so clear in hindsight,

The super-Earth in this illustration is in a planetary system whose central star is a red dwarf. Super-Earths are larger than our planet but smaller than Neptune, with masses up to 10 times that of Earth. *ASTRONOMY:* ROEN KELLY



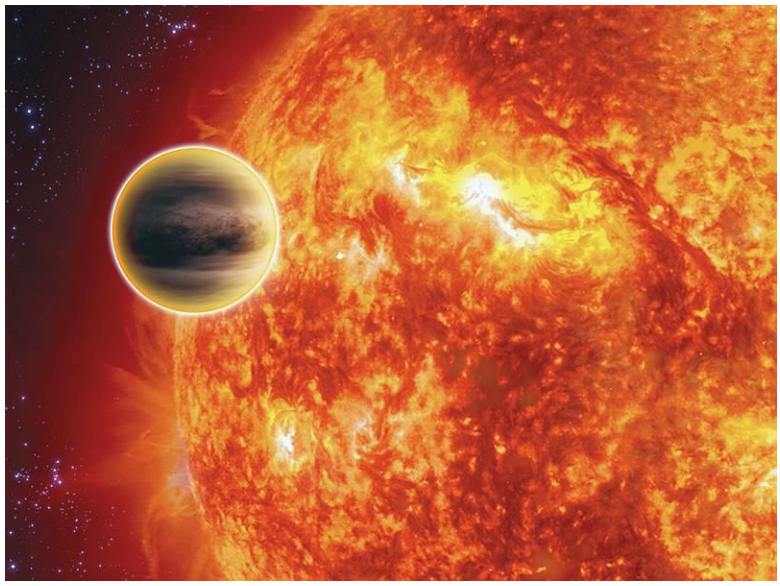
Kepler 1649c is an exoplanet whose size is only 6 percent greater than Earth's, and whose mass is only 20 percent greater. The biggest difference between the two is that Kepler 1649c orbits its star at a distance of only 6 million miles (9.7 million km) with an orbital period of 19½ days. NASA/AMES RESEARCH CENTER/DANIEL RUTTER

of using a single example of a phenomenon to reach a general conclusion. There are many ways, it turns out, to make a planetary system. The now-5,000-plus discoveries show that the most common type of exoplanet doesn't exist in our solar system at all.

Instead, the title of "most abundant" belongs to the class of super-Earths or sub-Neptunes, with masses between Earth's and Neptune's. Models of these planets typically envision solid cores of various sizes, surrounded either by varying amounts of hydrogen and helium (similar to jovian planets with larger cores) or by large amounts of water and thinner atmospheres. Those not much more massive than Earth may consist almost entirely of rock and metal.

Astronomers owe their increasingly productive and provocative flow of exoplanet knowledge to their use of ever more sensitive instruments. Some of these obtain data from telescopes on Earth, while others depend on spaceborne observatories. The latter includes both multipurpose facilities, such as the Hubble Space Telescope (HST) and the James Webb Space Telescope (JWST), and dedicated spacecraft, most notably the European Space Agency's CoRoT, which operated from 2006 to 2013; NASA's Kepler space telescope, which worked from 2009 through 2018; and its successor, NASA's Transiting Exoplanet Survey Satellite (TESS).

Because stars typically outshine their planets' weak reflected light by factors close to a billion or more, astronomers' most successful techniques for detecting exoplanets look to their stars. With increasingly precise measurements, they search either for tiny variations in a star's motion in response to a planet's gravitational force, or for minuscule changes in a star's brightness that occur when a planet passes in front of it. These two techniques, the radial velocity and transit methods, respectively, have revealed 93 percent of all verified exoplanets.



This artist's view shows 51 Pegasi b, the first exoplanet discovered around a Sun-like star. It lies some 50 light-years away and orbits only 5 million miles (8 million km) from its star. NASA/JPL-CALTECH

Discovery by radial velocity

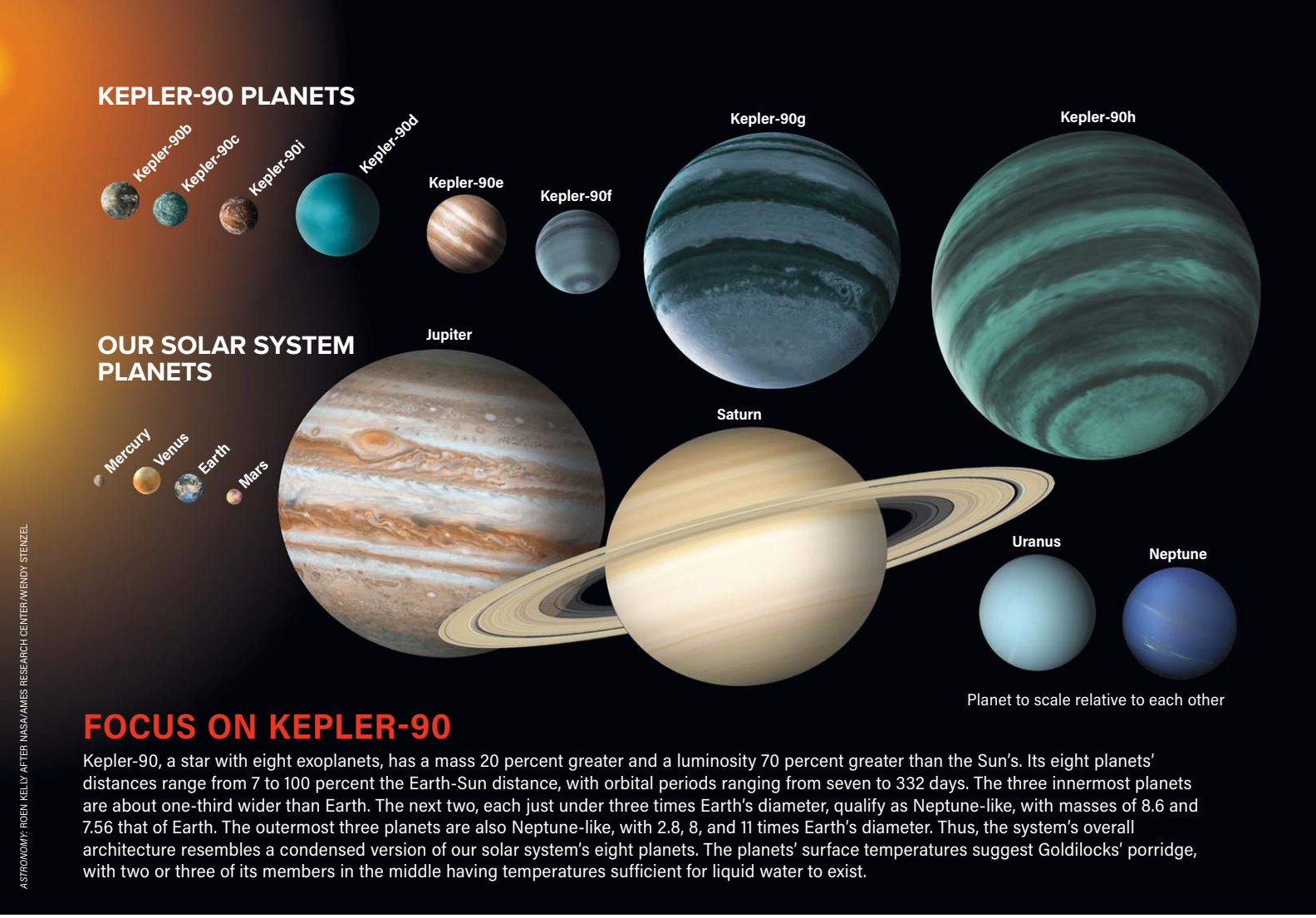
Radial velocity refers to a star's motion toward or away from us along our line of sight. For more than a century, astronomers have examined the spectra from stars, comparing observed wavelengths with laboratory values produced by known atoms and molecules at rest to reveal the composition as well as motion of stars.

Improvements in instruments and techniques now allow astronomers to measure these velocities to an accuracy close to a meter (a few feet) per second, a slow amble for a human. Observations that show repetitive, sinusoidal (up-and-down) deviations in a star's radial velocity indicate the presence of a planet, tugging the star back and forth as it orbits.

Radial velocity observations yield a surprising wealth of information about unseen planets. The time from one tug to the next is related to the planet's orbital period, and any deviations from a pure sine wave reveal the eccentricity of the orbit.

Because astronomers know the mass of the star (from their analysis of its spectrum), the planet's orbital period allows the calculation of the size of the planet's orbit, while the size of the up-and-down changes in the star's radial velocity reveals the planet's mass. Massive planets close to their stars produce the biggest, easiest-to-find signals — hence, those early massive exoplanet discoveries. One more parameter emerges from the type of star and the planet's distance: the planet's surface temperature in the absence of an atmosphere. Modelers can provide many more options for how that temperature could vary with different feasible atmospheres.

The radial velocity measurement technique can even discover



ASTRONOMY: ROEN KELLY AFTER NASA/AMES RESEARCH CENTER/WENDY STENZEL

FOCUS ON KEPLER-90

Kepler-90, a star with eight exoplanets, has a mass 20 percent greater and a luminosity 70 percent greater than the Sun's. Its eight planets' distances range from 7 to 100 percent the Earth-Sun distance, with orbital periods ranging from seven to 332 days. The three innermost planets are about one-third wider than Earth. The next two, each just under three times Earth's diameter, qualify as Neptune-like, with masses of 8.6 and 7.56 that of Earth. The outermost three planets are also Neptune-like, with 2.8, 8, and 11 times Earth's diameter. Thus, the system's overall architecture resembles a condensed version of our solar system's eight planets. The planets' surface temperatures suggest Goldilocks' porridge, with two or three of its members in the middle having temperatures sufficient for liquid water to exist.

multiple planets around a given star. In a multiple system, each planet imposes its own sinusoidal pattern on the star's radial velocity, adding to a seemingly tangled, superimposed mess. However, astronomers can disentangle it with proper analysis. The current record-holder belongs to a six-planet system, and we may reasonably expect even larger systems to emerge from this approach.

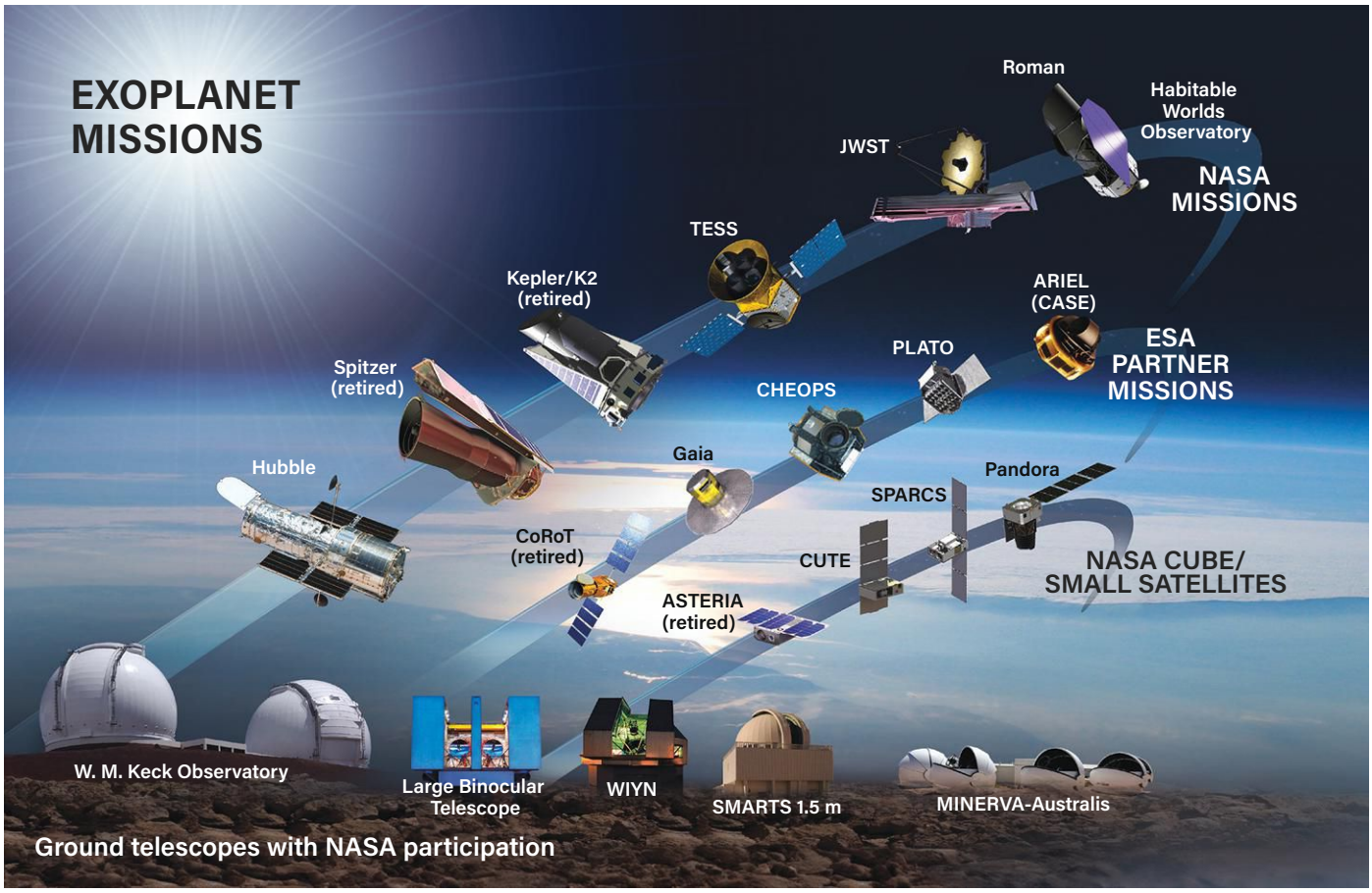
By now, radial velocity variations have revealed more than a thousand exoplanets, making it the second most successful discovery method. Observational programs across the globe continue to search for planets with this method, pushing the limits of detection to find ever more elusive worlds — those with smaller masses, orbiting farther away from their stars — planets like the ones we know in our own solar system.

Discovery by transit

The transit method is far and away the most successful way to discover exoplanets. Transit surveys monitor stars' brightnesses almost continuously, searching for minuscule dips that arise if a planet passes directly in front of the star, which recur regularly as a planet completes each orbit. This will occur only if the planet's orbital plane coincides almost exactly with our line of sight.

Because most exoplanet orbits lack this fortunate alignment, astronomers know full well that even their best instruments cannot find the majority of exoplanets using the transit technique, although smaller orbits increase the chance of alignments that produce transits. Almost in compensation for this incompleteness, transit observations provide not only the exoplanet's orbital period but also its size (though not its mass), because astronomers know the size of the star, revealed by its spectral characteristics.

The restless nature of Earth's atmosphere makes spaceborne observatories much better at detecting the tiny changes due to a transit in a star's brightness. If an extraterrestrial civilization observed transits of the Sun's planets, they would note a dip by 1 percent when Jupiter passed in front of the Sun, and 0.01 percent when Earth made its passage (five times more frequently). By our standards, verification of an exoplanet's existence requires at least three transit observations, so a Jupiter-sized planet in a Jupiter-sized orbit would take at least 10 years to achieve this status.



This graphic shows the spacecraft and observatories that are or have been engaged in exoplanet discovery and research.
NASA/JPL-CALTECH

Exoplanets discovered by the transit method offer a unique additional benefit. By comparing high-resolution spectroscopic observations of the star and planet during a transit with observations of the star alone, astronomers can determine whether the exoplanet has an atmosphere. If it does, they can even sometimes deduce the composition of that atmosphere from its contribution to the total spectrum.

Like radial velocity results, the rhythm of the transits caused by multiple planets in a system can be disentangled to reveal the size and orbital period of each world. Astronomers have applied this technique to discover one system with seven exoplanets, and another with eight. These planets all orbit in nearly the same plane (we would not detect them all otherwise), as the Sun's planets do. As with the radial velocity method, exoplanet detection by transits occur more readily around smaller, less luminous stars, whose planets produce larger changes in velocity and brightness. And although most of the systems with multiple planets we've found orbit comparatively smaller, low-mass, low-luminosity red dwarf stars, some do appear around stars more like our Sun.

Discovery by lensing

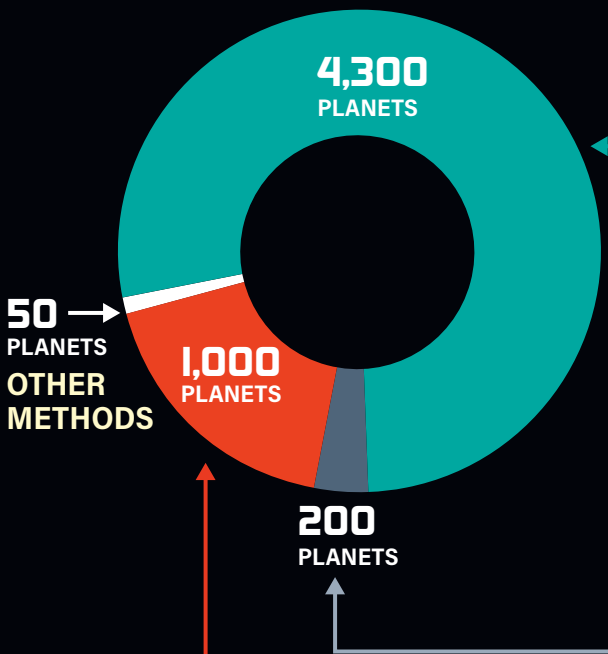
One more exoplanet discovery technique deserves attention for its impressive abilities (and its failings): gravitational lensing. As Einstein demonstrated, gravitational forces bend space, so a massive object that passes almost directly in front of a more distant source of light will change the path of light from the source, typically focusing it to produce a temporary increase in brightness. If a star's motion happens to carry it almost across the line of sight to a more distant star, gravitational lensing will brighten the light from the farther star for a few weeks or even months, based on typical stellar velocities.

Called microlensing events, the size and duration of these "blips" in stellar brightness increase with the mass of the foreground star that produces them. And within these blips, sometimes there is a much smaller, briefer blip, lasting perhaps hours, superimposed on the overall brightness curve. The smaller blip, which can be produced by a planet in orbit, reveals the planet's mass. Microlensing events can be observed even if the lensing star lies tens of thousands of light-years away. That distance is near or beyond the reach of the radial velocity and transit methods, most of which succeed for stars hundreds to a few thousand light-years away. Microlensing, however, has one great drawback: It is one and done. Once the foreground star has moved away from the farther star, no hope exists for a recurrence of that situation.

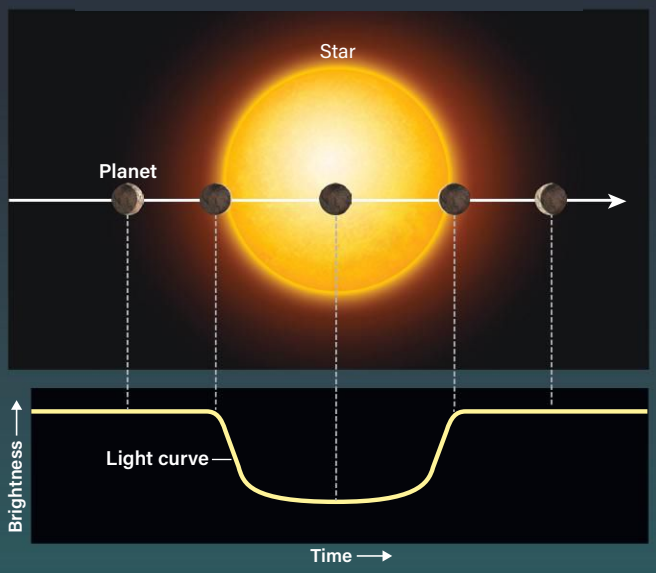
Ways to discover exoplanets

NUMBER OF PLANETS FOUND PER METHOD

As this chart shows, most exoplanets have been discovered by the transit method. The next most fruitful method is by studying the stars' radial velocities. Finally, gravitational lensing events are the third most productive way to find them. The "other" category has perhaps half of its number discovered by direct imaging. *ASTRONOMY*/ROEN KELLY



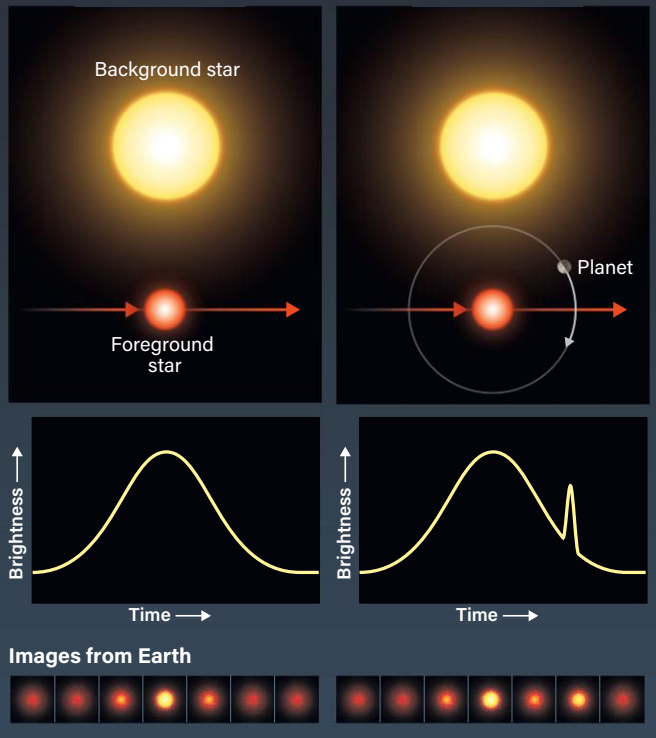
TRANSIT METHOD



Transits occur when a planet passes in front of its parent star from our point of view. As the planet transits, it blocks some of the star's light, causing a temporary dip in brightness that astronomers can use to identify planets, as well as determine their sizes and orbital periods.

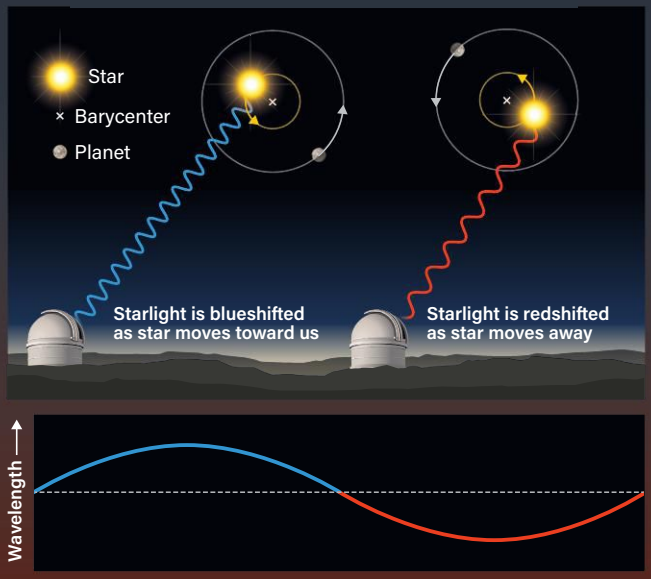
ASTRONOMY/ROEN KELLY AFTER NASA/AMES

GRAVITATIONAL LENSING



Discovering exoplanets using gravitational lensing works because when a foreground star (red) passes in front of a background star, it brightens the light of the background star. The gravitational field of the foreground star warps space to create a gravitational lens that magnifies light. If a planet is orbiting the foreground star, it too will gravitationally lens the background star for a shorter duration. *ASTRONOMY*/ROEN KELLY AFTER NASA/ESA/K. SAHU (STSCI)

RADIAL VELOCITY METHOD



A star-planet system orbits a common point called the barycenter. The radial velocity method watches for the telltale wobble as an orbiting planet tugs minutely on its sun, causing the star to move toward or away from Earth. This Doppler shifts the star's light slightly toward the blue or red end of the spectrum, respectively, revealing the planet's presence.

ASTRONOMY/ROEN KELLY

More discoveries coming

The ever-growing exoplanet census now includes more than 1,000 members in more than 800 planetary systems found by radial velocity observations, more than 200 discovered by microlensing effects, and some 4,300 revealed by their transits. Many more candidates await confirmation via future observations. More complex and subtle methods have added several dozen additional planets to the overall list, with 82 more planets (as of this writing) from the straightforward but highly difficult approach of direct imaging.

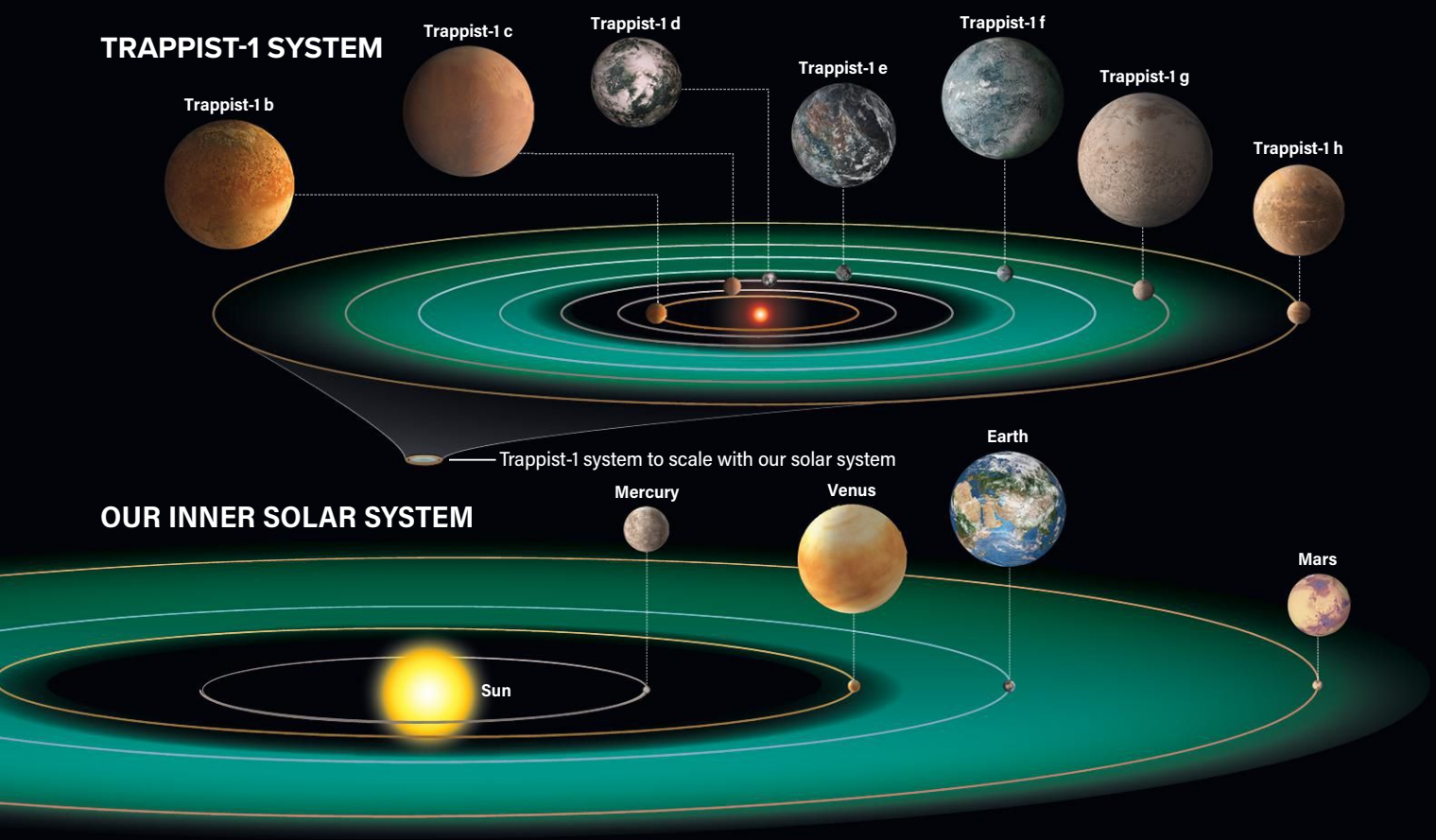
Future exoplanet discoveries follow a dual pathway: detection of more planets, especially with new instruments, and superior analysis of exoplanets already on the list. Today, astronomers have three primary (but nowhere near the only) instruments to discover and examine planets in the Milky Way. One more should soon join them, while a fifth, the most powerful, will — if all goes well — begin operation in 20 years or so.

The three instruments that currently return some of the biggest streams of useful data are TESS, HST, and JWST. The next on the list, the Nancy Grace Roman Space Telescope, has a scheduled launch date in mid-2027, while the fifth — with the greatest potential for exoplanet discoveries — is the Habitable Worlds Observatory (HWO), still in development. While astronomers promoting and guiding HWO remain highly enthusiastic, commentators often note that the slow bleed of funding for NASA's most ambitious projects casts some doubt of having the spacecraft ready for launch in the mid-2040s, as currently planned.

Within the next few years, TESS's more than 7,200 exoplanet candidates should yield at least another 1,000 confirmed planets, as repeated transit observations verify them. Astronomers can then combine transit data with radial velocity measurements made with giant ground-based telescopes to verify and improve the accuracy of the orbital data derived from TESS's observations. Many of TESS's newfound worlds, as well as those discovered by other planet-finding techniques, furnish a rich field of study for JWST, and a lot

FOCUS ON TRAPPIST-1

Seven exoplanets orbit a star called TRAPPIST-1, which possesses only 9 percent the Sun's mass and ½,₀₀₀ its luminosity. The closest exoplanet to the star is slightly more massive than Earth and takes a day and half for each orbit at a distance ¹⁄₁₀₀ as far as Earth's. Its daytime side maintains a temperature of 450 degrees Fahrenheit (230 degrees Celsius). The farthest exoplanet, with one-third Earth's mass, orbits 5½ times farther out and has a surface temperature close to minus 160 F (minus 100 C). Both planets lie outside the star's habitable zone, the region where liquid water might exist. This favored attribute belongs to the fourth-, fifth-, and sixth-closest planets, with masses equal to 0.7, 1.03, and 1.3 times Earth's.



ASTRONOMY: ROEN KELLY AFTER NASA/JPL-CALTECH

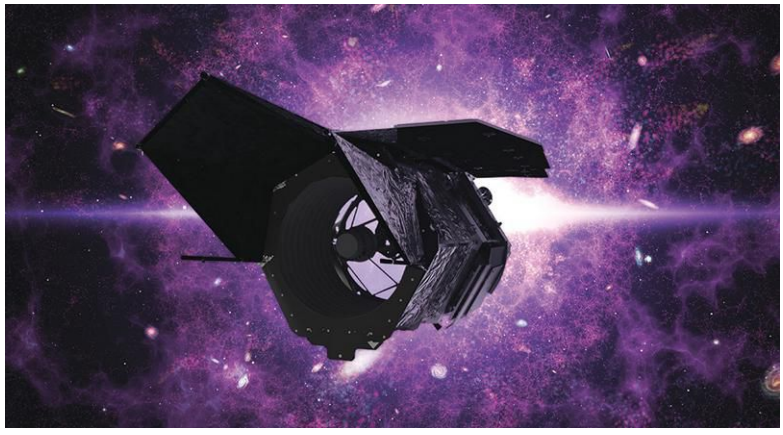
of observational time with the mighty telescope has been reserved for exoplanet follow up.

Hoped-for discoveries

Astronomers will gain even more exoplanet observations when Roman joins JWST in orbit around Earth's second Lagrangian point — a spot that provides orbital stability — some 930,000 miles (1.5 million kilometers) farther from the Sun than Earth. Like HST, Roman will have a mirror 2.4 meters in diameter. Unlike HST, though, Roman will employ just two instruments: a wide-field camera and a coronagraph. The camera will observe the cosmos in infrared radiation as well as visible light, and will secure images as detailed as Hubble's, but over a field of view 10 times wider.

Roman's first-of-a-kind visible-light and infrared coronagraph will use a series of masks, prisms, and deformable mirrors to block the direct light from a star and feed the remaining light from the star's surroundings into a high-contrast camera and spectrometer. This should allow the coronagraph to obtain images and spectra of planets with as little as one-hundred-millionth of their parent star's brightness, revealing and characterizing exoplanets similar to Jupiter in diameter and orbital distance.

Jupiter-like planets have their merits, but the ultimate goal of exoplanet hunters naturally centers on securing images of Earth-like planets — those with about one-tenth Jupiter's diameter, orbiting their stars at distances that would allow liquid water to exist on their surfaces. To achieve this goal, astronomers require a much larger instrument: HWO, with a mirror as large as the 6.5-meter mirror on JWST. And some astronomers envision one considerably larger. Although this spacecraft would investigate both solar system objects and distant galaxies, its name reflects its primary mission: to discover and study potentially habitable worlds.



Astronomers hope the Habitable Worlds Observatory will launch in the 2040s. It will provide a high-level tool to search for exoplanets. NASA

The Nancy Grace Roman Space Telescope will discover new exoplanets by identifying gravitational lensing events. NASA

To accomplish these goals, HWO would employ spectroscopy to look for biosignatures in exoplanet atmospheres, as well as direct imaging using a coronagraph. The more ambitious plans for HWO call for a sunshield, whose orbit near HWO would keep it positioned to block almost all light from the target star. The reason for such a proposal is that blocking starlight can be more complete before light enters a telescope, rather than after.

A sunshield working in tandem with HWO's coronagraph would finally create an instrument capable of securing images of exoplanets whose reflected light, like Earth's, falls more than a billion times below their star's brightness. MIT professor Sara Seager, one of the leaders in the hunt for exoplanets, has set as her chief professional goal "to find another Earth." This means a planet the size of ours, moving in a similar orbit around a Sun-like star. She has stated in a number of interviews, "As a human species, we want to find something like our own [planet]," she notes, demonstrating that astronomers experience the same emotions as the rest of us when we consider the grand variety of planets in the Milky Way.

Will this require another 20 years? If so, the 50th anniversary of the first exoplanet discoveries could mark the time when humans find Earth's near-twin in the Milky Way.

Donald Goldsmith *is an astronomer and science writer in Berkeley, California. His latest books are* Exoplanets *and* The End of Astronauts: Why Humans Are the Future of Space Exploration *(with Martin Rees).*

Lunar landings aren't just the province of global superpowers anymore.

BY ROBERT REEVES

THE NEW GOLDEN AGE OF MOON EX

DURING THE COLD WAR, the U.S. and USSR raced to be first to send robotic and human explorers to the Moon, traversing lunar terrain and returning samples to Earth. These exploits and their scientific returns were crucial to unlocking the history of the Moon — and by extension, the history of our solar system.

But after these initial forays, exploration of our natural satellite hit the doldrums. Following the USSR's Luna 24 sample-return mission in 1976, the Moon's surface remained undisturbed by visitors for decades, save for the occasional impact.

Finally, the 1990s saw a revival in robotic lunar exploration as the U.S. and Europe carried out flybys and Japan deployed its first lunar orbiter. This movement gained steam in the 2000s as China and India launched their first robotic missions to the Moon. And in 2013, China's Chang'e 3 touched down on the Moon — the first soft lunar landing in 37 years.

Today, a new golden age of lunar exploration is in full swing. Although the return of humans to the Moon on crewed Artemis landings remains years away, robotic explorers are already pushing ahead, exploring new regions and deepening our understanding of this ancient, airless world. The rate of scientific return is only set to increase as companies like SpaceX and Blue Origin show promise in expanding access and driving down costs using reusable rockets.

As a result, the Moon is no longer the domain of the two traditional space superpowers; instead, Luna has become a scientific target studied by many nations and private companies.

Robotic landers lead the way

NASA's Artemis program has evolved into an effort of staggering complexity. (See "Artemis explained" in our January 2024 issue for more.) Technological and funding issues cloud exactly when new human footprints appear on the Moon and NASA's optimistic lunar exploration timetables frequently become fiction. Realistically, the Artemis 3 mission will land a crew on the Moon no earlier than 2028 — if NASA doesn't settle for a flyby — and the agency will have spent $93 billion to do so.

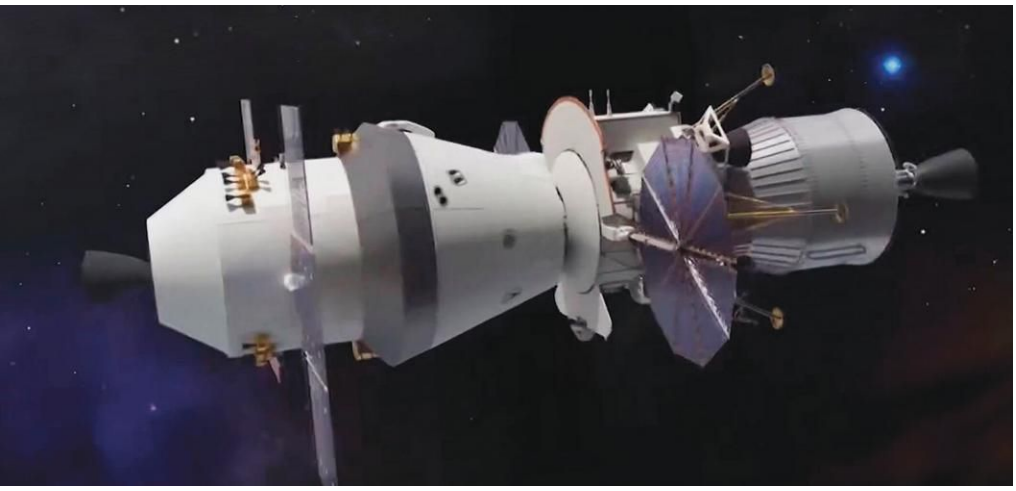
Robotic explorers are crucial to the Artemis program's goals, serving as technology testbeds and scouting possible landing sites for resources. To give those efforts a boost, NASA has fundamentally changed its approach to lunar robotic exploration and now relies on commercial services to deliver science experiments to the Moon.

In 2020, NASA initiated the Commercial Lunar Payload Services (CLPS) project to encourage affordable and rapid delivery of science payloads to the Moon. With the first wave of contracts, startups like Astrobiotics, Firefly Aerospace, and Intuitive Machines took

ABOVE: India's domestically developed Launch Vehicle Mark 3 launched the Chandrayaan-3 mission on July 14, 2023. The subsequent successful landing of the Vikram lunar lander on Aug. 23, 2023, marked India as the fourth nation to land on the Moon. ISRO

LEFT: Firefly Aerospace has developed a lunar orbiter (named Elytra) and a lander (Blue Ghost, pictured here) that will launch for the first time in early 2025, carrying 10 payloads for NASA to the lunar surface. FIREFLY AEROSPACE

PLORATION



China's lunar ambitions include a crewed landing in the 2030s using the Mengzhou spacecraft (at left in this illustration) and the Lanyue lunar lander (at right). CNSA

WHO OWNS THE MOON?

IN JULY 1969, NEIL ARMSTRONG AND BUZZ ALDRIN planted the American flag on the Moon's Sea of Tranquility — though not as an act of conquest, nor a proclamation of ownership. Indeed, no nation has legal ownership nor exclusive rights to the Moon. But future disputes over such issues are practically inevitable.

The largest effort to create a framework for the modern politics of lunar exploration is the Artemis Accords, an international agreement spearheaded by the U.S. in 2020; as of November 2024, they have been signed by 48 nations. The crux of the document proclaims activities on the Moon shall be for peaceful purposes in accordance with international law. Scientific lunar data should be transparently shared and major lunar infrastructure systems should be compatible across nations. Further, efforts should be made to assist anyone in space who is in distress and all objects in space will be registered. The accords also provide for preserving space heritage locations and sharing resources under international law.

A challenge facing the ambitious cooperative umbrella of the Artemis Accords is the absence of China and Russia as signatories. To date, China's International Lunar Research Station (IRLS) has signed Russia, Venezuela, Pakistan, the United Arab Emirates, and the Asia-Pacific Space Cooperation Organization (APSCO) as active partners.

The reality is that soon multiple nations, as well as private corporations, will have the technical means to conduct crewed landings on the Moon. Space law experts are calling upon U.S. leaders to engage China about future lunar governance and bring China and its partners into the Artemis Accords. Not doing so risks the creation of two spheres of influence on the Moon that could aggravate political tensions on Earth. *—R.R.*

their place alongside established aerospace industry giants. By late 2024, eight CLPS missions had flown or were in advanced development. Of those, three targeted the Moon's nearside, three targeted the little-explored farside, and three aimed for the region near the lunar south pole. The south pole is a key region of interest: Due to the Sun's low angle on the horizon, many of its craters have areas that lie permanently in shadow and harbor water ice that could be used by crews living in future Moon habitats.

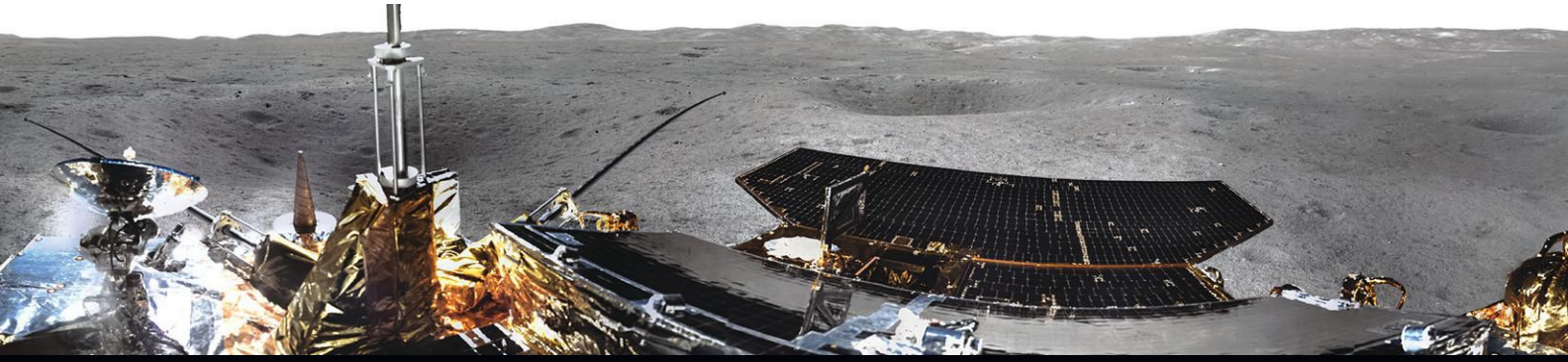
The initial commercial lunar missions have reminded us that the Moon remains a harsh mistress. Three of the first eight uncrewed landings in NASA's CLPS program have either failed to complete their missions or been canceled just as the mission was ready to fly.

Astrobiotic's Peregrine Mission One was the first CLPS payload to fly in January 2024, but a catastrophic fuel leak hours after launch doomed the mission and the spacecraft fell back to Earth after 10 days in space.

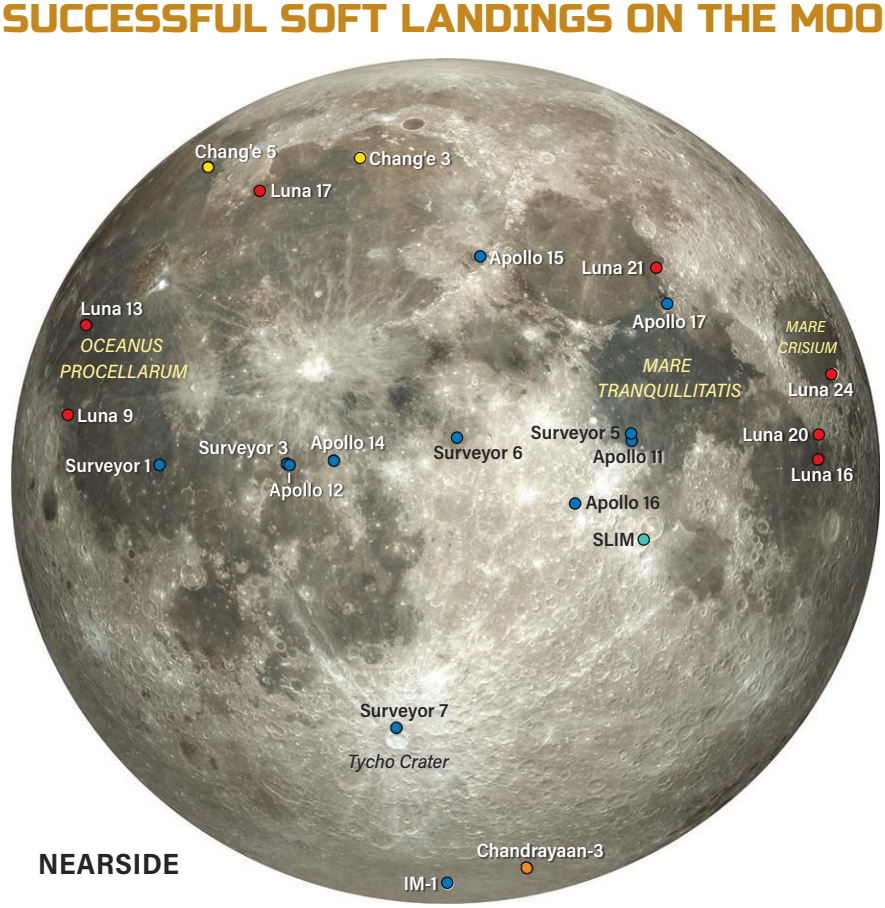
The second CLPS mission in February 2024 was a partial success. The Intuitive Machines IM-1 mission Nova-C lander, nicknamed Odysseus, landed in the crater Malapert A near the lunar south pole, but skidded across the surface as it touched down, snapping a landing leg. The craft came to rest tipped at a 30° angle, but was able to return a limited amount of data before losing power.

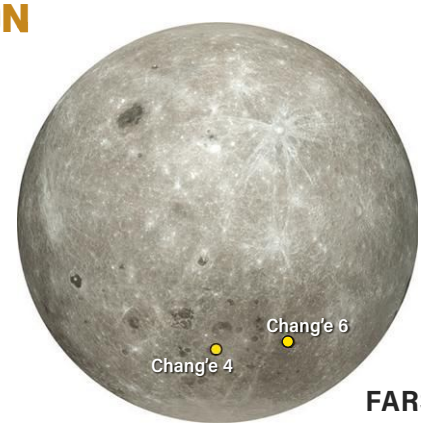
Intuitive Machine's next mission, IM-2, will land the Polar Resources Ice Mining Experiment (PRIME-1) near Shackleton Crater. The mission is set for an early 2025 launch aboard a SpaceX Falcon 9, a proven rocket that will launch many CLPS payloads. A drill attached to the lander will bore into the lunar soil and search for evidence of water ice. Sharing a ride aboard IM-2 will be a collection of rovers. These include Japan's palm-sized Yaoki; the Lunar Outpost Mobile Autonomous Prospecting Platform (MAPP), which will hopefully travel up to 1.2 miles (2 kilometers) with a tiny AstroAnt mini-rover riding piggyback; and the Micro-Nova rover, which is designed to hop around permanently shadowed crater floors.

BELOW: China's Chang'e 4 lander returned a dramatic panorama of its farside landing site with the Yutu-2 rover in the distance. CNSA



SUCCESSFUL SOFT LANDINGS ON THE MOON





KEY
- United States
- Soviet Union
- China
- India
- Japan

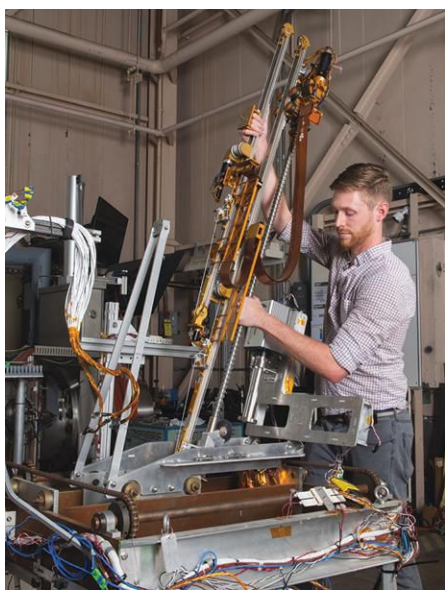
As of November 2024, 25 missions have achieved successful soft landings on the Moon and completed at least some of their mission goals. (Luna 23 tipped over on its side and could not return samples to Earth; later, Luna 24 was sent to the same location.) *ASTRONOMY*: ROEN KELLY. BASEMAPS: NASA/GODDARD SPACE FLIGHT CENTER/ARIZONA STATE UNIVERSITY

Also scheduled for early 2025 is the Firefly Aerospace Blue Ghost mission, which will land near Mons Latreille on Mare Crisium, delivering 10 experiments.

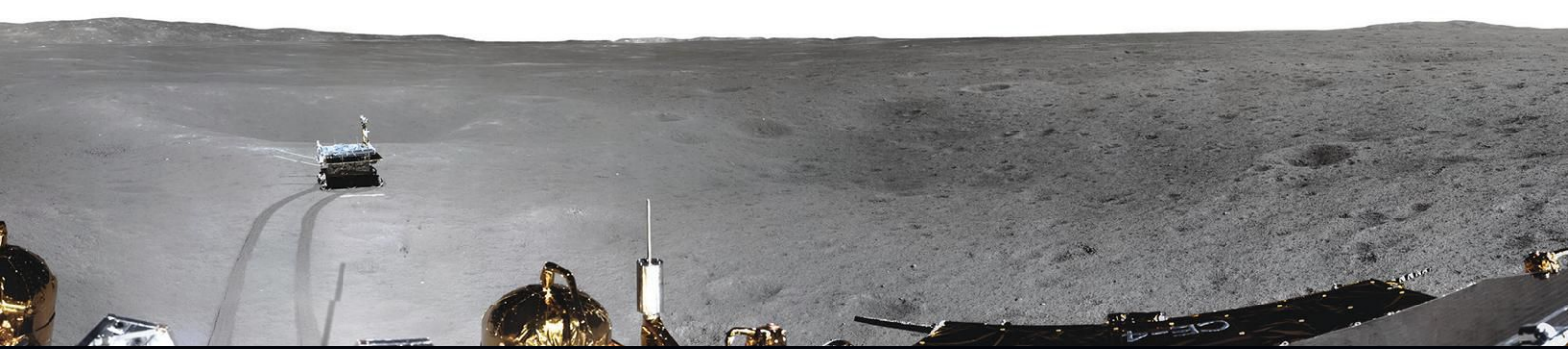
Later in 2025, Intuitive Machines' IM-3 will attempt to land near the enigmatic swirl-shaped feature Reiner Gamma on Oceanus Procellarum. The origin of such lunar swirls remains a mystery, but possible explanations include past or present magnetic anomalies. IM-3 will carry instruments to study the magnetic and electric fields near Reiner Gamma, and will also deploy another MAPP rover.

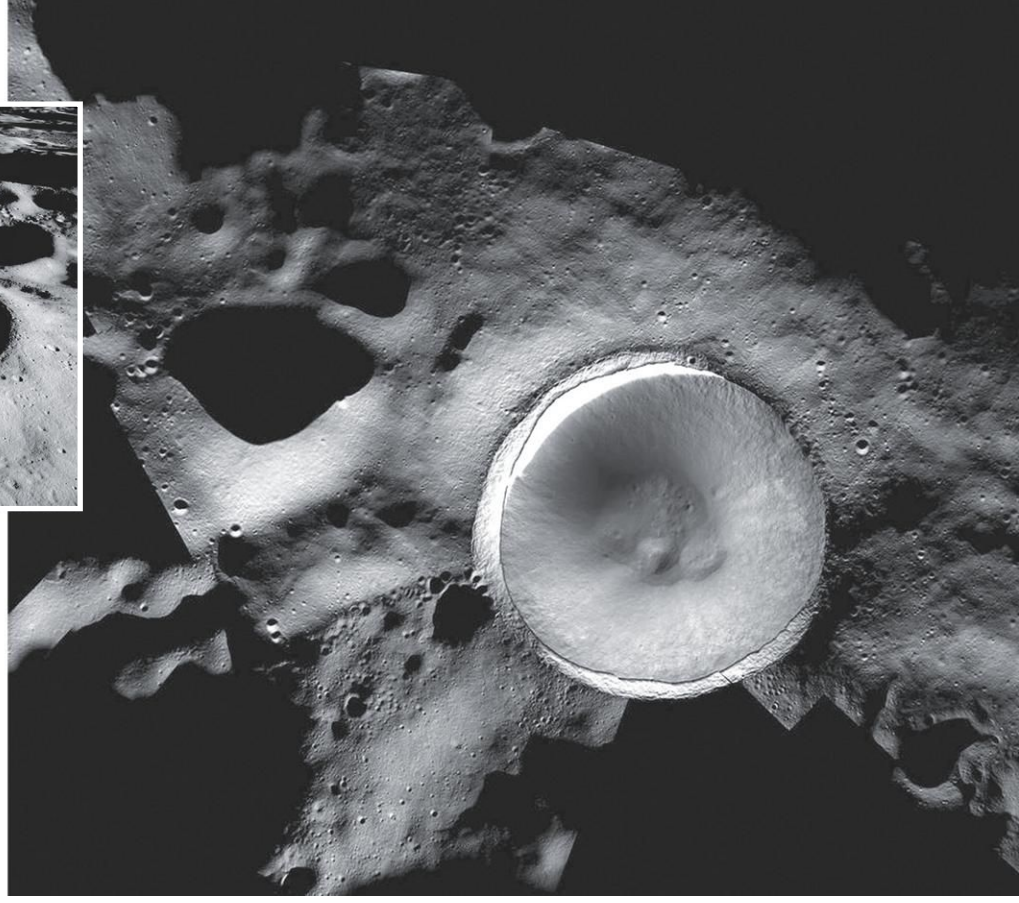
Unfortunately, in July 2024, NASA cancelled the 2025 flight of the already completed Volatiles Investigating Polar Exploration Rover (VIPER). Instead, the agency plans to land VIPER's former ride, the Astrobiotic Griffin lander, with no science payload at all.

The CLPS program will progress in 2026 with the Draper SERIES-2 lander targeting the Schrödinger Basin on the Moon's farside. The Farside Seismic Suite will investigate seismic activity using instruments adapted from the 2018 Mars Insight mission that detected 1,300 marsquakes. The mission will also deploy two small relay satellites to allow the farside lander to communicate with Earth. The second 2026 CLPS payload will be the Firefly Aerospace Blue Ghost 2, which will land a radio astronomy experiment on the radio-quiet farside of the Moon. The mission will also deliver the



Once scheduled to prospect for lunar ice aboard the VIPER lunar rover, the Honeybee Robotics TRIDENT ice drill will now only operate from the fixed landing site of the Intuitive Machines IM-2 mission. HONEYBEE ROBOTICS





Shackleton Crater lies in the crucial south pole region and much of its floor is permanently shadowed (top left). The image at above reveals what lies in the shadowed region thanks to data collected by a NASA-built camera called ShadowCam, mounted to South Korea's first lunar orbiter, named Danuri (Enjoy the Moon). The image is a composite; the region surrounding the crater's interior is data taken from NASA's Lunar Reconnaissance Orbiter. FROM LEFT: NASA'S SCIENTIFIC VISUALIZATION STUDIO; MOSAIC CREATED BY LROC (LUNAR RECONNAISSANCE ORBITER) AND SHADOWCAM TEAMS WITH IMAGES PROVIDED BY NASA/KARI/ASU

REWRITING LUNAR HISTORY

THE NEW WAVE OF INTERNATIONAL ROBOTIC EXPLORATION is already bearing scientific fruit and changing the established timeline of the Moon's formation.

India's Chandrayaan-3 mission has contributed to our understanding of the Moon's early history. Its landing site is farther south than any other soft landing, with the exception of IM-1. Yet data from that mission's Pragyan rover published in August 2024 shows that the composition of anorthosite rocks at that location are remarkably similar to those returned by Luna and Apollo missions that landed over 1,100 miles (1,800 kilometers) to the north. That likeness suggests that these rocks all came from a global primordial ocean of magma that covered the Moon just after it was formed in a cataclysmic collision between Earth and a Mars-sized body.

Meanwhile, China's Chang'e missions are revealing just how long the Moon remained volcanically active. In all of the rocks returned by the Luna and Apollo missions, no volcanic rocks have been identified younger than 3 billion years old. But basalt rocks returned by Chang'e 5 from the ancient lava plain of Oceanus Procellarum are just 2 billion years old, scientists reported in October 2021.

Even more stunning are the possible implications of a few tiny glass beads found among Chang'e 5's sample: An analysis published in September 2024 suggests that they are volcanic in origin and a mere 125 million years old. Taken together, the Chang'e 5 results indicate that volcanoes erupted on the Moon for much longer than expected — perhaps well into the age of the dinosaurs on Earth. — *R.R.*

European Space Agency's Lunar Pathfinder relay satellite into lunar orbit.

The Moon goes global

In addition to the NASA-subsidized commercialization of the Moon, lunar exploration has become a truly international endeavor. As of late 2024, the international fraternity of lunar efforts includes Russia, the U.S., Japan, the European Space Agency (representing 22 European countries), China, India, Luxembourg, Israel, South Korea, Italy, United Arab Emirates, Mexico, and Pakistan.

In 2025, Canada's Jeremy Hansen will fly on Artemis 2, becoming the first non-American to go to the Moon. Two astronauts from the European Space Agency (ESA) and two from Japan will be chosen for lunar flights, possibly as early as Artemis 4 or 5. And in an agreement with the UAE, the first Emirati to travel to the Moon will fly aboard an Artemis mission early in the next decade.

China has made amazing strides in robotic lunar exploration. In 2013, it became the third nation to deploy a lunar rover with the Chang'e 3 mission. Chang'e 4 in 2018 became the first spacecraft to make a soft landing on the Moon's farside. And with Chang'e 5 in 2020 and Chang'e 6 in May 2024, China returned samples from the near and far sides of the Moon, respectively, with the latter feat being another world first.

Historically, when China announces ambitious space plans, they become reality. There is no reason to doubt China's stated intention to land astronauts on the Moon in the 2030s.

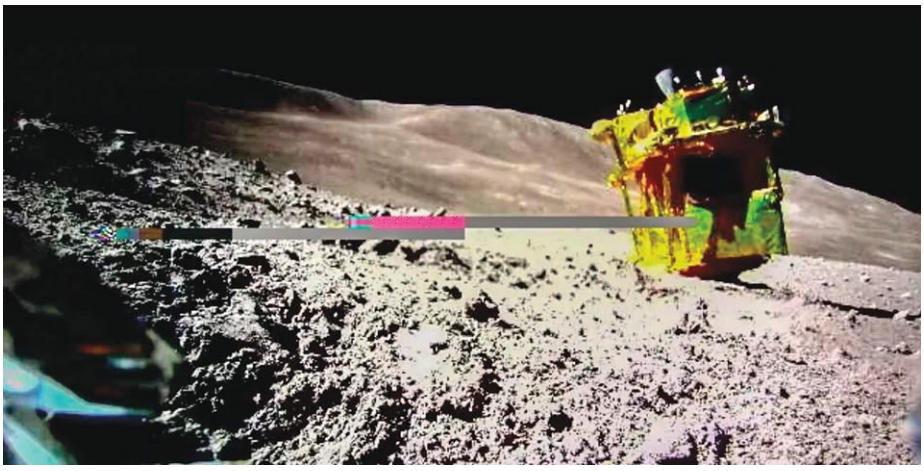
Current plans call for an uncrewed 57,000-pound (26,000 kilograms) Lanyue (Embrace the Moon) lander to be sent to lunar orbit by a Long March 10 rocket. The crewed Mengzhou (Dream Vessel), also launched by a Long March 10, will rendezvous with the Lanyue and the astronauts will descend to the surface in the lander. A rover with a 6-mile (10 km) range will allow extended exploration. After leaving the Moon, the crew will return to Earth aboard Mengzhou. Subsequent Chinese plans include establishing a basic Moon base by 2035,

expanding to a lunar station by 2045 in partnership with 10 other nations.

India is now a spacefaring power and also has ambitious lunar plans. India's 2008 Chandrayaan-1 lunar orbiter provided convincing evidence of water ice on the Moon. A lunar landing attempt in 2019 failed, but in August 2023, the Vikram lander successfully touched down and deployed the Pragyan rover near the Moon's south pole. The achievement marked India as the fourth nation to land on the Moon. India's plans for a crewed lunar landing in the 2040s are in their early stages, but India possesses the technology to accomplish that goal.

Japan became the fifth country to land on the Moon when its Small Lander for Investigating the Moon (SLIM) made a precision landing near Theophilus Crater in January 2024. Unfortunately, the lander came to rest nearly upside down, limiting the amount of power supplied by its solar cells. Two small rovers were successfully deployed, and SLIM remained in contact with Earth for two months (four lunar days).

The Japanese company ispace is preparing its Hakuto-R Mission 2 carrying the Resilience lander and Micro Rover for an early 2025 launch. Additionally, Japan is partnering with India for the joint Lunar Polar Exploration (LUPEX) project. Japan will provide a Mitsubishi H3 rocket to propel the Chandrayaan-4 lander to the Moon in 2026 where it will deploy a 770-pound (350 kg) rover carrying NASA and ESA instruments to search for ice at the lunar south pole.



On Jan. 19, 2024, Japan became the fifth nation to land on the Moon when its Small Lander for Investigating the Moon (SLIM) landed near Theophilus Crater. Although images returned from the deployed Lunar Excursion Vehicle (LEV) Rover showed the craft tipped over onto its nose, SLIM remained in contact with Earth for four lunar days. JAXA

After the cancellation of NASA's VIPER rover, LUPEX is the next opportunity to use a rover-mounted surface drill and spectrometer to search for ice in the Moon's shadowed south polar region.

Risk and reward

Not every mission on this new lunar frontier is a success. The Israeli Beresheet (In the Beginning) lander — attempting the first lunar landing by a private company — suffered an engine problem and crashed in April 2019. (Undeterred, Beresheet 2 is scheduled for flight in 2025.)

In December 2022, Japan's Hakuto-R Mission 1 lander crashed on the Moon when a software fault resulted in the craft hovering 3 miles (5 km) above the surface until it ran out of fuel.

And the Russian Luna 25 lander — attempting to pick up the torch from 1976's Luna 24 — impacted the Moon in August 2023 when an orbit-lowering burn lasted longer than commanded.

Both the successes and failures recall President John F. Kennedy's 1962 declaration that we accept challenges like going to the Moon "not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills." The ongoing surge of interest in lunar exploration represents a new global wave of energy and skill — and scientists and space aficionados the world over will be its beneficiaries.

Robert Reeves *is an accomplished astrophotographer and author with a passion for lunar photography and science.*

When the Intuitive Machines Odysseus lander touched down on the Moon in February 2024, it was carrying excess horizontal velocity. This snapped off one of the craft's landing legs (below) causing it to tip over (inset). INTUITIVE MACHINES (2)

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.
BY MARTIN RATCLIFFE AND ALISTER LING

A total lunar eclipse will wow North and South America this month as the Moon passes through Earth's penumbra, as it did during the November 2022 eclipse pictured here. DYLAN O'DONNELL

MARCH 2025

A total lunar eclipse

A total eclipse of the Moon is the highlight of this month, visible across North and South America. Venus remains very bright and transitions from evening to morning late in the month. Mercury joins Venus for a few evenings, offering the best opportunity to see both planets in twilight. Mars and Jupiter dominate the late evenings, providing many hours of planetary observation with tantalizing features to see in small scopes.

Both the inner planets, Mercury and Venus, stand together in the evening twilight during early March. Look for them soon after sunset. They will appear near the western horizon, so avoid any obstacles that may hamper your view.

Venus will be most obvious because it is so bright, shining at magnitude –4.8 on March 1. It becomes obvious within 30 minutes of sunset. On that date, a slender crescent Moon stands 6.5° due south (to the lower left) of Venus. Mercury, at magnitude –1, hangs nearly 10° below the Moon. Catch them all within an hour of sunset.

Watch Venus through a telescope this month. From the 1st to the 15th, the 49"-wide disk showing a 14-percent-lit crescent transforms into a 3-percent-lit crescent spanning 58" — quite a dramatic change over two weeks.

Venus drops quickly into bright twilight in the third week of March and passes through inferior conjunction on the 22nd, standing some 9° north of the Sun. However, it is too dangerous to try and spot in daytime, due to the risk of sunlight entering your telescope.

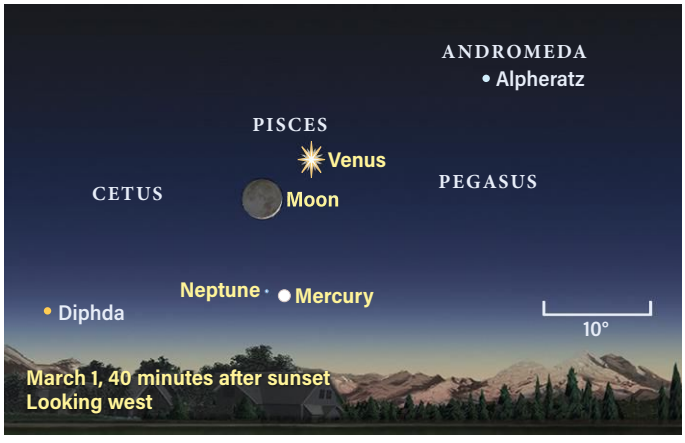
Venus quickly reappears in the morning sky. By the 31st, it rises in the east an hour before sunrise. Through a telescope, its slender crescent now spans 57" and is 4 percent lit.

Neptune, too faint to see (magnitude 7.8), stands 2° to the left (southeast) of Mercury on the 1st. It reaches superior conjunction with the Sun on the 19th. **Saturn** is also lost in the Sun's glare and reaches superior conjunction on the 12th.

As March progresses, **Mercury** climbs higher to meet Venus. They appear side by side on the 13th, although Mercury has faded to magnitude 0.5 by this time; Venus is magnitude –4.4. They're 5.5° apart. The alignment is a line-of-sight effect, as Venus stands closer to Earth (0.29 astronomical unit [AU]; 1 AU is the average Earth-Sun distance), while Mercury is on the far side of its orbit (at 0.77 AU). Both planets descend into twilight within a week, and we lose sight of them.

Uranus stands near the border of Aries and Taurus, crossing into Taurus on the 3rd. On March 4, a waxing crescent Moon stands nearby. Swing binoculars to the Moon and scan 4.5° south to spot Uranus, shining at magnitude 5.8. The 5th-magnitude star 63 Arietis lies half that distance from the Moon and provides a useful guide to find Uranus, which is

Twilight scene



March opens with Venus and Mercury visible in the evening sky, along with a delicate crescent Moon. Neptune is nearby but likely not visible in twilight, even with optical aid. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

THE MOON undergoes a total lunar eclipse overnight on March 13/14.

2.3° (a little over four Moon-widths) due south of the star.

By the 23rd, Uranus is 11' due south of a 7th-magnitude field star. The planet dips low in the western sky by the end of the month. On the 31st, the crescent Moon is again rising to meet Uranus. The ice giant is 8° east of the Moon on this last evening of the month.

Jupiter shines brightly in Taurus the Bull, starting the month at magnitude –2.3 and dimming to magnitude –2.1 by the 31st. Jupiter moves east during the month, extending its distance from Aldebaran, the brightest star in Taurus, from 5° to 8°. A nearly First Quarter Moon stands 7° from Jupiter on the 5th.

Jupiter sets by 1 A.M. local daylight time at the end of the month and offers long evening views in small telescopes of its Great Red Spot, the twin dark equatorial belts, and other atmospheric features. Its disk spans 39" on the 1st and falls to 36" by the 31st, as the distance between Earth and the giant planet increases.

Io, Europa, Ganymede, and Callisto orbit Jupiter with periods ranging from about two to 17 days. In addition to wandering east and west of the planet, they become hidden behind the disk or transit in front it. Their shadows appear as a black dot slowly moving across the cloud tops over a couple of hours.

Ganymede, Europa, and Io share a 1:2:4 resonance in their orbital periods, so similar events repeat. March 11/12 finds both Europa and Ganymede's shadows on the disk at the same time, from about 11 P.M. to 12:45 A.M. EDT.

The eastern half of the U.S. sees Ganymede off the western limb, with Europa in transit. Watch the eastern limb of Jupiter for the appearance of Europa's shadow around 10:15 P.M. EDT, around the same time Europa is exiting the disk. Next up is the giant shadow of Ganymede, which appears on Jupiter's southeastern limb about half an hour later. It takes more than 10 minutes to fully appear.

— *Continued on page 34*

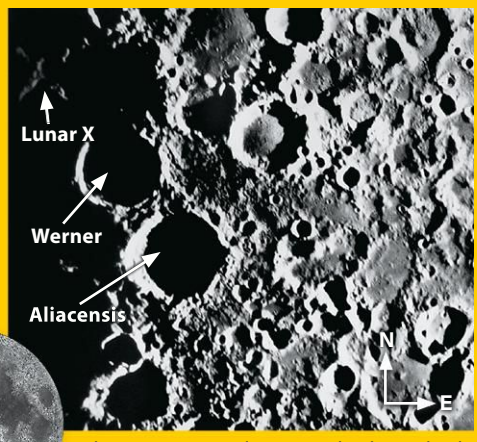
RISING MOON | X marks the spot

OBSERVERS IN NORTH AMERICA are perfectly placed to watch a few points of light on the Moon evolve into a prominent letter X on the evening of the 6th. It's just a chance alignment of light and shadow as the Sun rises over a group of crater walls, but fun to see because it tickles our pattern-recognition fancy, called pareidolia.

If you take video clips every five to 10 minutes, you can create a time-lapse movie of the X emerging, peaking, and disappearing all in one evening. In the east, start looking soon after sunset. Focus in on a spot about halfway between the equator and the south pole, using the twin craters Aliacensis and Werner as your guide to the X, just to their northwest.

Watch points of light evolve into arcs, then full circles all up and down the terminator.

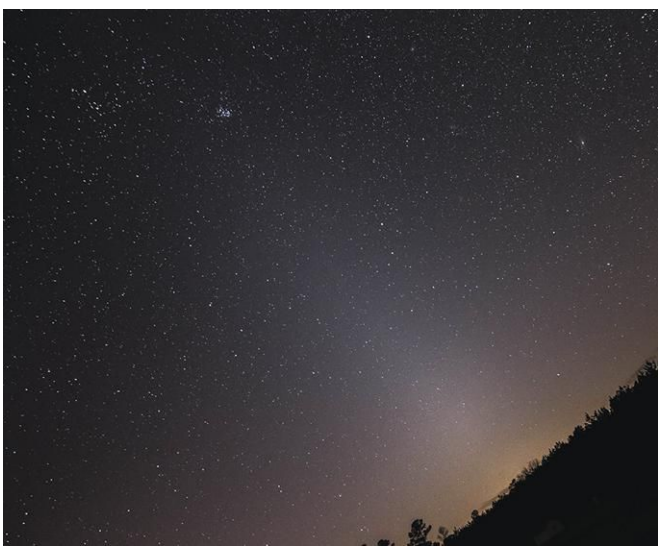
The Lunar X



The Lunar X sometimes goes by the Purbach Cross or Werner X, referring to the nearby named craters. *CONSOLIDATED LUNAR ATLAS*/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Dusty glow

Bright pillar



In spring, the zodiacal light rises up into Pisces, Aries, and Taurus. STEPHEN RAHN

EARLY SPRING is not well known for meteor showers, with no major events occurring this month. It is, however, a great month to spot the zodiacal light. The best opportunities occur when the Moon is out of the way, in the first three days of March and again during the last two weeks of the month.

Look for a delicate cone-shaped glow extending above the horizon through Pisces, Aries, and Taurus. Try using peripheral vision to spot the arching cone of light by scanning your eyes left to right along the western horizon. You'll need a clear, dark horizon unaffected by lights or distant city glows, which mask the effect.

The zodiacal light is aligned with the ecliptic, Earth's orbital plane, and comes from sunlight reflecting off fine, dusty debris littering the inner solar system, left over by passing comets long ago.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. March 1
10 P.M. March 15
9 P.M. March 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

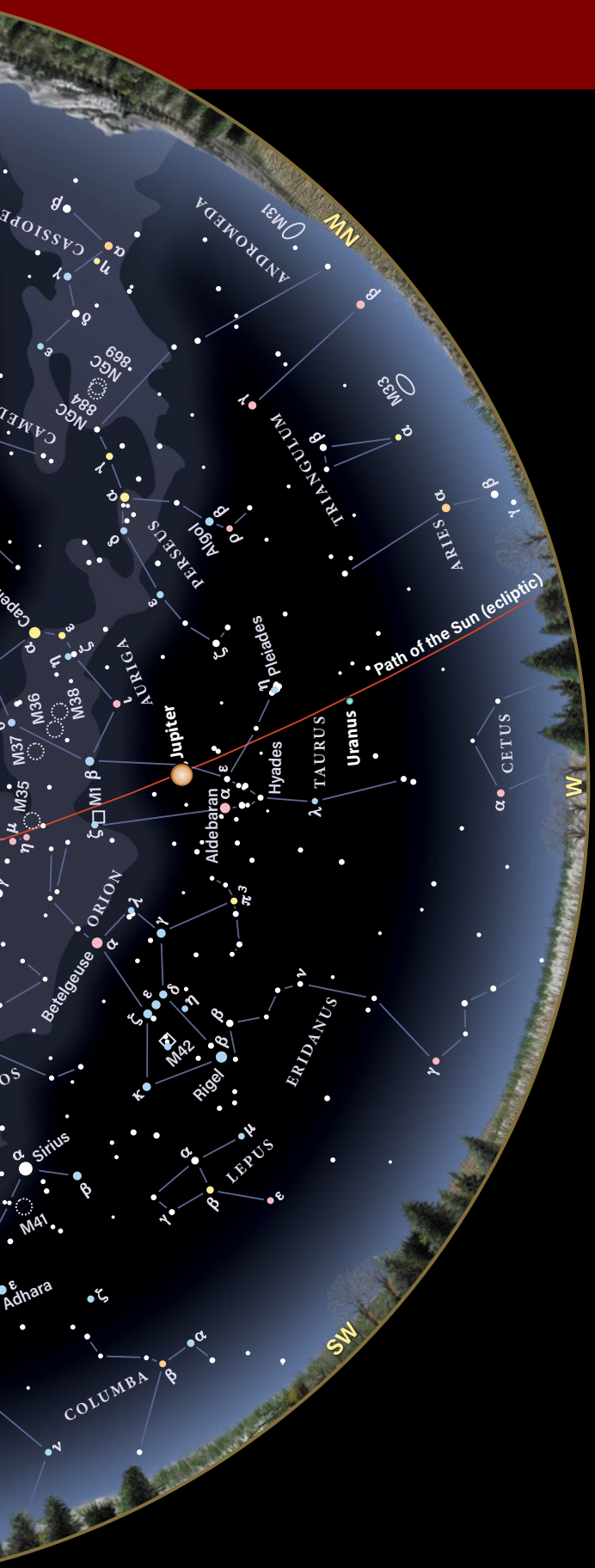
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



MARCH 2025

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 The Moon passes 1.6° north of Neptune, 4 A.M. EST
The Moon is at perigee (224,914 miles from Earth), 4:21 P.M. EST
The Moon passes 6° south of Venus, 6 P.M. EST

4 The Moon passes 5° north of Uranus, 11 P.M. EST

6 The Moon passes 6° north of Jupiter, 7 A.M. EST
First Quarter Moon occurs at 11:32 A.M. EST

8 Mercury is at greatest eastern elongation (18°), 1 A.M. EST
The Moon passes 1.7° north of Mars, 7 P.M. EST

9 Mercury passes 6° south of Venus, 7 A.M. EDT

12 Saturn is in conjunction with the Sun, 6 A.M. EDT
Asteroid Flora is at opposition, 6 P.M. EDT

14 Full Moon occurs at 2:55 A.M. EDT; total lunar eclipse
Mercury is stationary, 5 P.M. EDT

16 The Moon passes 0.4° south of Spica, 4 P.M. EDT

17 The Moon is at apogee (252,124 miles from Earth), 12:37 P.M. EDT

19 Neptune is in conjunction with the Sun, 7 P.M. EDT

20 Vernal equinox occurs at 5:01 A.M. EDT
The Moon passes 0.5° south of Antares, 1 P.M. EDT

22 Last Quarter Moon occurs at 7:29 A.M. EDT
Asteroid Juno is stationary, 2 P.M. EDT
Venus is in inferior conjunction, 9 P.M. EDT

23 Asteroid Vesta is stationary, 1 A.M. EDT

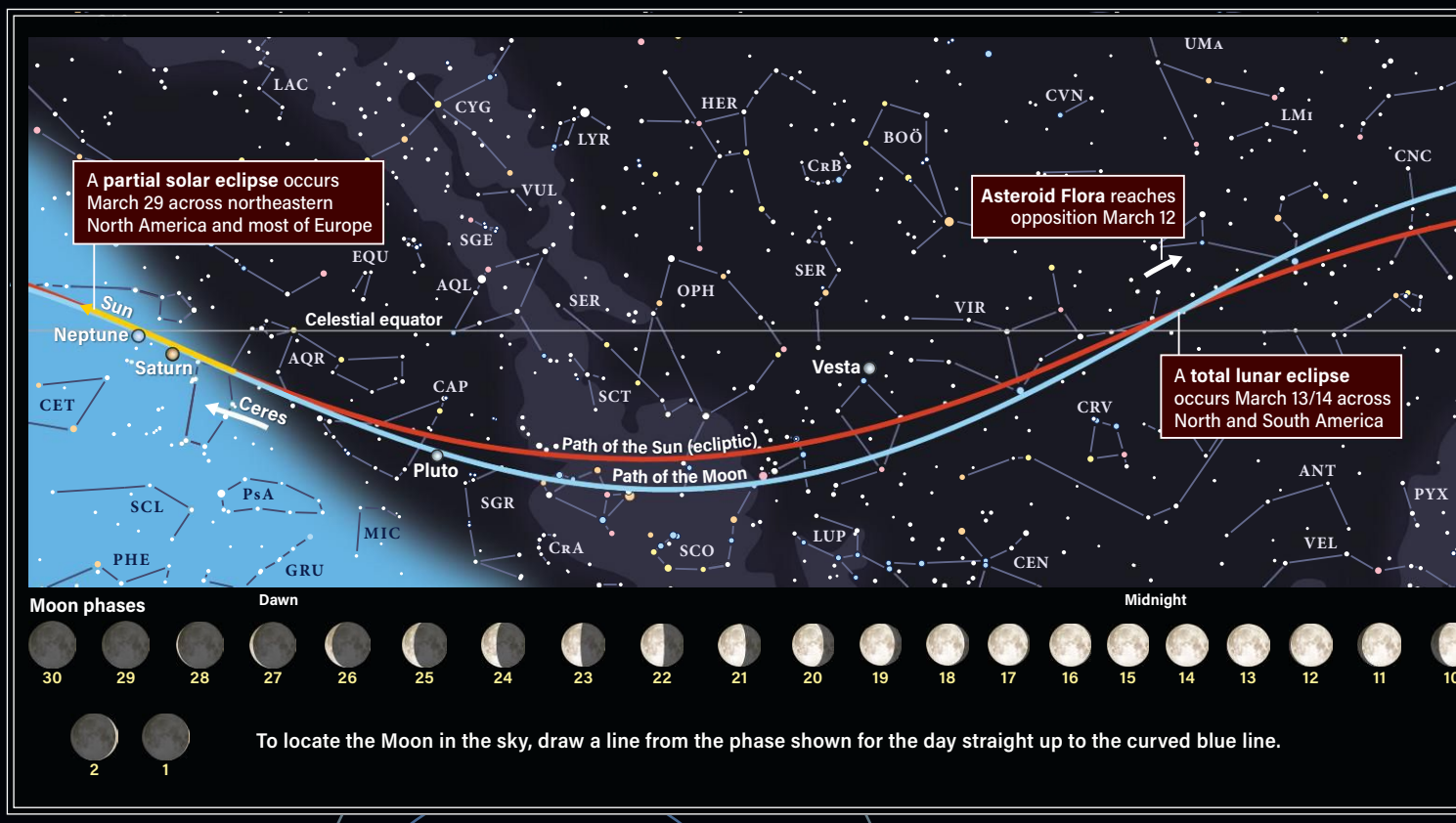
24 Mercury is in inferior conjunction, 4 P.M. EDT
The Moon passes 0.9° south of Pluto, 5 P.M. EDT

28 The Moon passes 9° south of Venus, 10 A.M. EDT

29 New Moon occurs at 6:58 A.M. EDT; partial solar eclipse

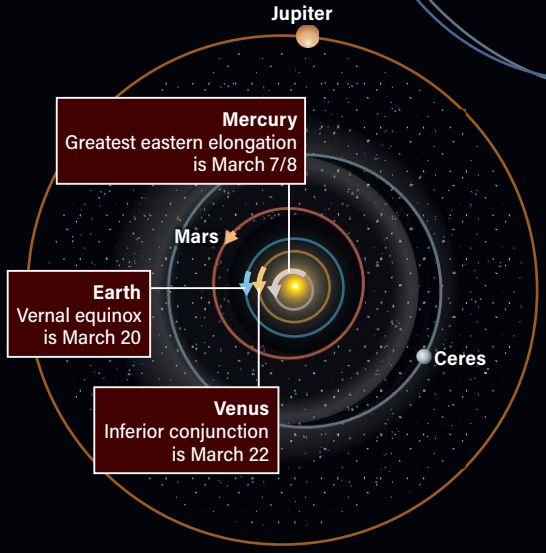
30 The Moon is at perigee (222,530 miles from Earth), 1:25 A.M. EDT
Venus passes 10° north of Saturn, 2 A.M. EDT

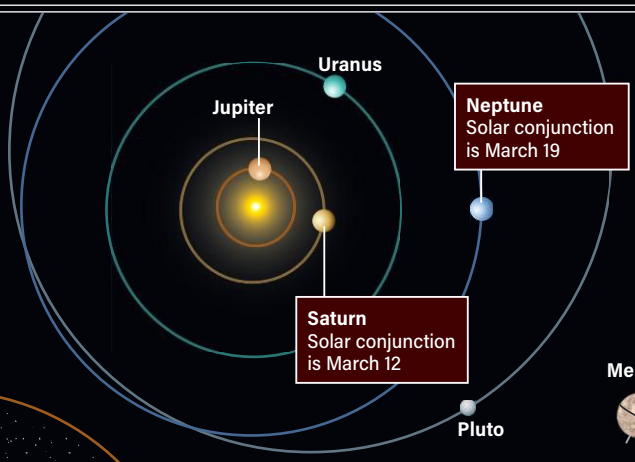
PATHS OF THE PLANETS

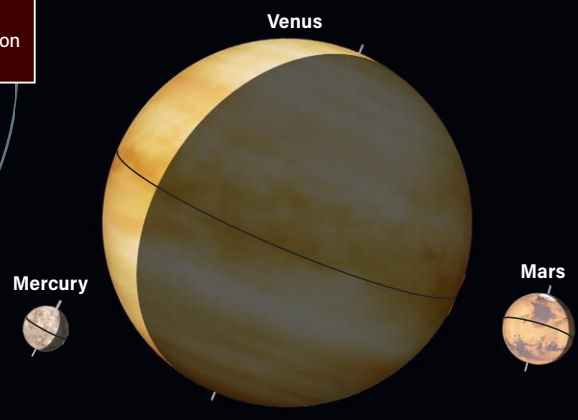


THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.



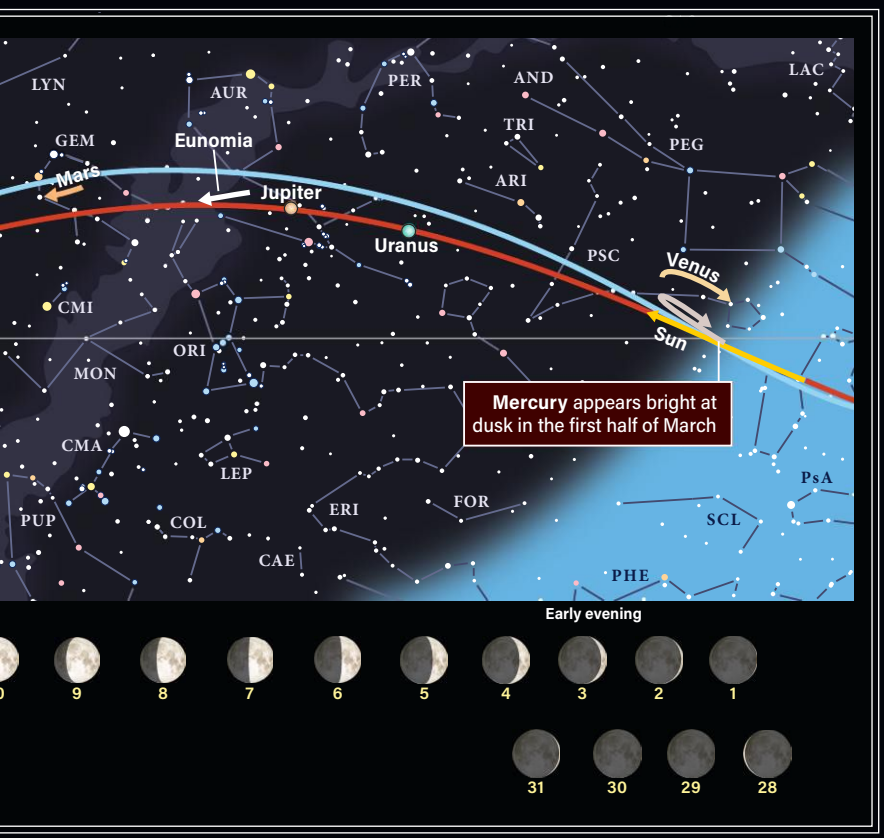




PLANETS	MERCURY	VENUS
Date	March 1	March 1
Magnitude	–1.0	–4.8
Angular size	6.0"	48.7"
Illumination	76%	15%
Distance (AU) from Earth	1.114	0.342
Distance (AU) from Sun	0.312	0.719
Right ascension (2000.0)	23h44.7m	0h27.8m
Declination (2000.0)	–1°24'	10°18'

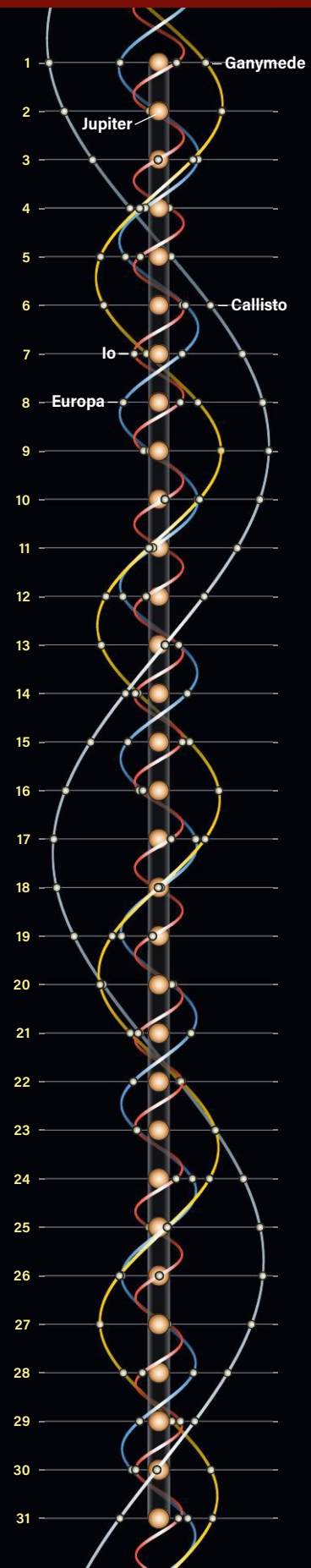
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

MARCH 2025



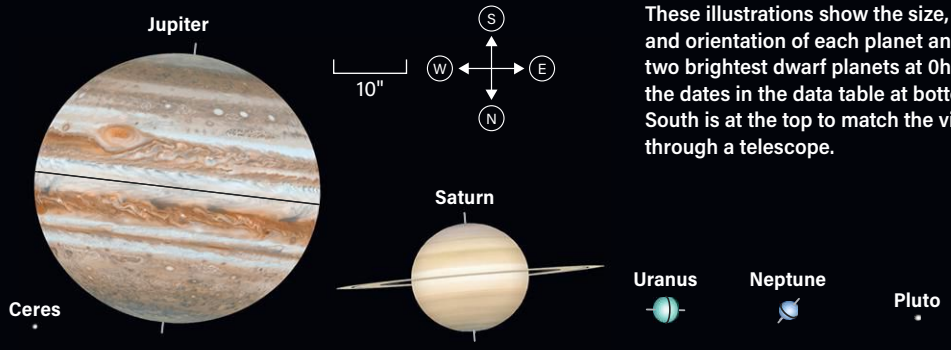
JUPITER'S MOONS

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.



THE PLANETS IN THE SKY

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
March 15	March 15	March 15	March 1	March 15	March 15	March 15
0.1	9.2	−2.2	1.1	5.8	7.8	15.3
9.5"	0.3"	37.9"	15.7"	3.5"	2.2"	0.1"
92%	100%	99%	100%	100%	100%	100%
0.982	3.910	5.203	10.586	20.028	30.883	35.831
1.661	2.986	5.107	9.613	19.541	29.892	35.221
7h22.8m	22h46.9m	4h47.8m	23h27.5m	3h25.6m	23h58.6m	20h24.1m
25°14'	−16°00'	22°03'	−5°35'	18°29'	−1°32'	−22°49'

 — Continued from page 29

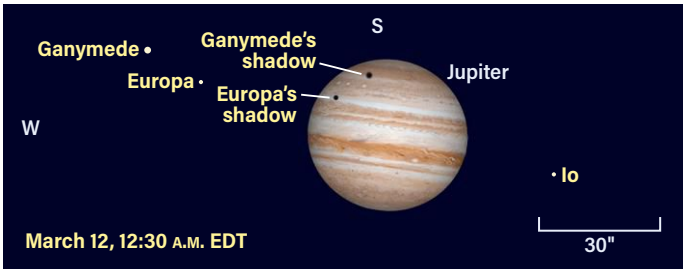
WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (west)
Venus (west)
Mars (southeast)
Jupiter (west)
Uranus (west)
Neptune (west)

MIDNIGHT
Mars (west)
Jupiter (west)

MORNING SKY
Venus (east)

Twin shadows



The shadows of Ganymede and Europa cross the face of Jupiter together March 11/12. At the time shown here, Io has just emerged from eclipse within Jupiter's shadow; Callisto lies farther east.

Europa's shadow transit ends at 12:50 A.M. EDT, followed some 20 minutes later by the beginning of Ganymede's shadow exit.

A week later, on the 18th, both moons transit the disk, starting with Ganymede around 9:30 P.M. EDT, as Europa hovers off the eastern limb. Europa begins its transit nearly an hour later, at 10:18 P.M. EDT. Meanwhile, watch Io disappear behind Jupiter's western limb shortly after 10:50 P.M. EDT.

Ganymede ends its transit around midnight EDT. Watch the eastern limb for Europa's shadow ingress at 12:50 A.M. EDT (now March 19 in the Eastern time zone), followed by Europa leaving the western limb five minutes later. These later events occur with Jupiter at low altitude or setting for the eastern half of the U.S.

The following night, March 19, Io is transiting the disk, visible for East Coast observers as darkness falls. Io leaves the disk around 10:20 P.M. EDT., with its shadow near Jupiter's meridian. The shadow exits just before 11:40 P.M. EDT, visible across the U.S.

On the 25th, Europa and Ganymede again gather at Jupiter's eastern limb, but their transits are only visible from the western half of the U.S. Europa's transit begins just before midnight CDT; Ganymede's begins around 11:40 P.M. MDT. Note how Europa has overtaken Ganymede since March 18, when its transit began nearly an hour after Ganymede's. Now Europa leads by nearly 45 minutes.

Once again, Io follows a day later, with a transit starting at 10:05 P.M. EDT. Its shadow appears around 11:18 P.M. EDT.

On the 27th, Io and Europa reappear from the long shadow extending behind Jupiter. Io exits its eclipse at 10:45 P.M. EDT, about 20" from the northeastern limb of Jupiter. Europa is following, but takes until 11:50 P.M. CDT to reappear, some 32" from the same limb.

Mars is visible all night and stands high in the east at sunset, located in central Gemini. It forms a nice triangle with Gemini's brightest stars, Castor and Pollux. The Red Planet shines at magnitude –0.3 on the 1st and dims to magnitude 0.4 by the 31st. A gibbous Moon stands some 2° northeast of Mars on the 8th. Mars stands 8' northeast of 5th-magnitude 57 Geminorum on March 15th.

Telescopic views become more challenging as the distance to Mars increases. Its apparent diameter shrinks from 11" to 8" during the month, placing the planet well past its best. Very noticeable is the accompanying change of phase, as Mars diminishes from 94 percent to 90 percent lit.

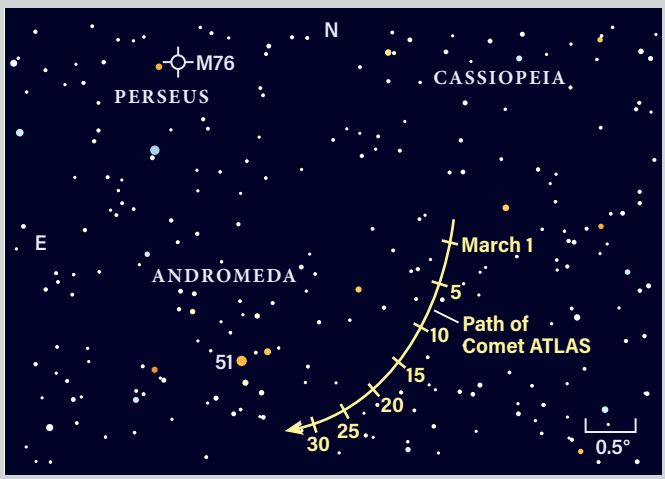
Features on Mars become more difficult to make out as the disk shrinks. Can you see the North Polar Cap? It is melting as Mars moves toward northern summer. During

COMET SEARCH | Plumbing the Depths

THE POPULARITY of the deep sky increased as larger scopes became affordable, inspiring comet fans to coin their viewing as "shallow-sky," perhaps to entice galaxy fans to check out our solar system's primordial snowballs. However, the only known comets coming up will require 10-inch or larger scopes to go deep from a dark site.

C/2022 E2 (ATLAS) is a 12th-magnitude pollen puff floating near the butterfly-winged nebula M76. Its curving trajectory keeps it within 2° of 51 Andromedae, which glows an easy magnitude 3.6 in any finder scope. Zero in on the field and push the power past 150x, even to 250x. The overall view will be darker, but the 1'- to 2'-wide comet then has a chance to tickle the dark-adapted rods of your retina.

Comet C/2022 E2 (ATLAS)

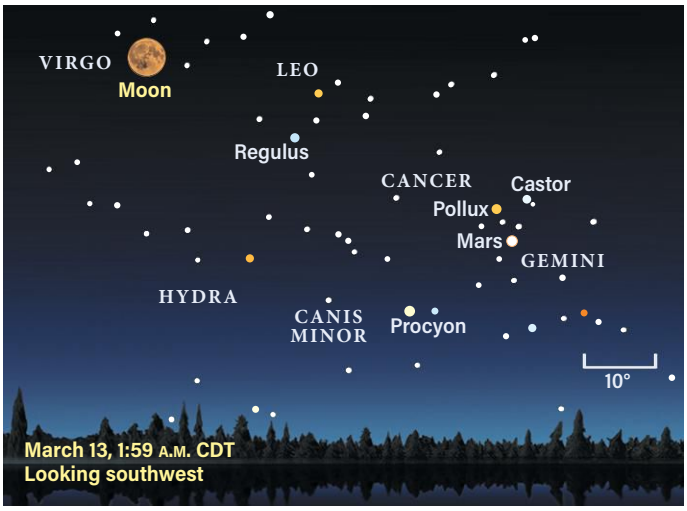


Compare the shapes of "warm-up" galaxies NGC 910 and NGC 911 (outside this field of view) to the southeast to that of ATLAS — are any lopsided?

Perhaps start to the southeast with the spectacular 10th-magnitude edge-on NGC 891 near Gamma (γ) And, and its companions NGC 910 and NGC 911, glowing at magnitude 12.3 and 12.7, respectively.

And drop in on 29P/Schwassmann-Wachmann in Leo — it could be in outburst at 11th magnitude. Take in some color along the way, from blue-white Regulus to orange R Leonis, the latter of which is 1.5° north of the comet in early March.

The Moon in eclipse



This illustration shows the southwestern sky from the mid-U.S. at the time of greatest eclipse (2:59 A.M. EDT, 1:59 A.M. CDT).

March it may change quickly.

The first week of March is the best time to view the darkest feature on Mars, Syrtis Major. On the 1st, it's visible as soon as it's dark and rotates off the disk within a few hours. By the 7th, Syrtis Major is on the eastern limb of the planet at dusk across the central U.S. Over the next eight hours, you can follow it to the western limb.

Once Syrtis Major has gone, the fingerlike dark feature Sinus Meridiani appears at the eastern limb. As March progresses, this feature appears later each night.

During the last week of the month, the Tharsis ridge and Olympus Mons face Earth. By the end of March, the Solis Lacus region, including Valles Marineris, returns to our view.

This month's total eclipse of the Moon occurs March 13/14, visible across North and South America. It's also visible near dawn across the U.K., Ireland, Spain, Portugal, and parts of western Europe. The Moon lies near the border between Leo and Virgo.

A total lunar eclipse is the result of the Full Moon passing directly into Earth's shadow. It's a fine alignment that doesn't occur every month because of the Moon's 5° orbital tilt.

The barely noticeable penumbral stage begins just before 11:56 P.M. EDT. Gradually the southeastern limb of the Moon becomes dusky, until the Moon enters the main shadow at 1:09 A.M. EDT.

The partial phase gradually covers each crater in progression, and soon the dark shadow takes on a deep orange glow, with photographs easily revealing color. It's the result of sunlight filtering through Earth's atmosphere, which scatters blue light and allows red light to continue on to the lunar surface. This initially subtle coloration is particularly noticeable through a telescope. The color of the eclipsed Moon can vary between a dusky gray to a brilliant orange, dependent upon the state of Earth's atmosphere.

The latter half of the partial phase is stunning, as many stars come into view as the Moon darkens further. Totality begins just after 2:25 A.M. EDT and greatest eclipse occurs at 2:59 A.M. EDT. The Moon is crossing the northern part of Earth's shadow, resulting in some 66 minutes of totality.

Totality ends at 3:32 A.M. EDT, and the final partial phase progresses until 4:48 A.M. EDT. The final penumbral trace leaves the disk by 6:02 A.M. EDT.

It's a perfect eclipse for photography. Wide-angle lenses capture constellations, with the orange Moon hanging like a lantern in the sky. Telescopic images reveal low-contrast craters on the Moon bathed in the orange glow.

Note that many states in the U.S. change to daylight saving time on March 9.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

LOCATING ASTEROIDS
Lounging with Leo

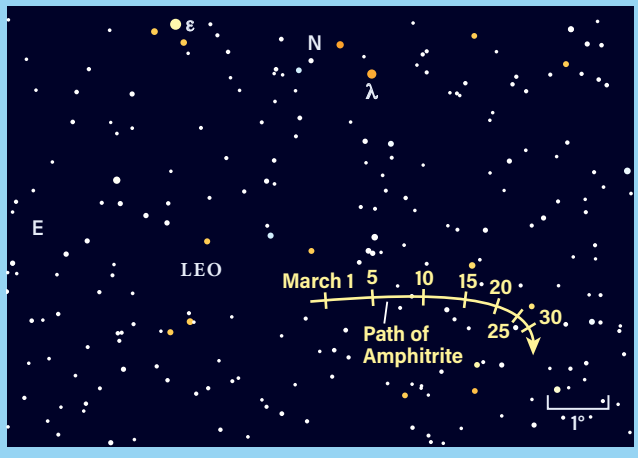
REGULUS is the sparkling beacon in the east almost halfway up the sky during March evenings. Also known as Cor Leonis, the heart of the Lion, Regulus anchors a pattern of stars called the Sickle, which for modern observers resembles a backwards question mark. (Few folk these days have held a sickle, a common tool of farmers of the past.)

29 Amphitrite sports a diameter of 124 miles, shining with reflected sunlight at magnitude 9.5, and this month curves 4° south of Lambda (λ) Leo. Far from the Milky Way, the background here is sparse, making pattern recognition easy to identify the space rock. On the 9th, Amphitrite looks like the fainter component of a wide double, sitting just over an arcminute from an 8th-magnitude field star. Return three hours later to see that it has almost doubled that separation.

Named for a sea goddess in Greek mythology, this classic main-belt asteroid orbiting beyond Mars was discovered by German astronomer Albert Marth while working in London on March 1, 1854.

While you're at the neck of the Lion, drop by Gamma (γ) Leo, one of the sky's showcase double stars, a striking pale orange sun across a 5"-wide gap from a gold spot.

South of the Sickle's crook



Amphitrite is traveling through the region just south of Lambda Leo and northwest of Regulus (outside this field of view).

HOW BIG WERE THE FIRST

JWST's Near-Infrared Camera captured this galaxy-filled field as part of the Cosmic Evolution Early Release Science Survey. Some of the most distant galaxies, which formed within 1 billion years of the Big Bang, appear brighter than they otherwise would because they contain accreting supermassive black holes. NASA, ESA, CSA, STEVE FINKELSTEIN (UT AUSTIN)

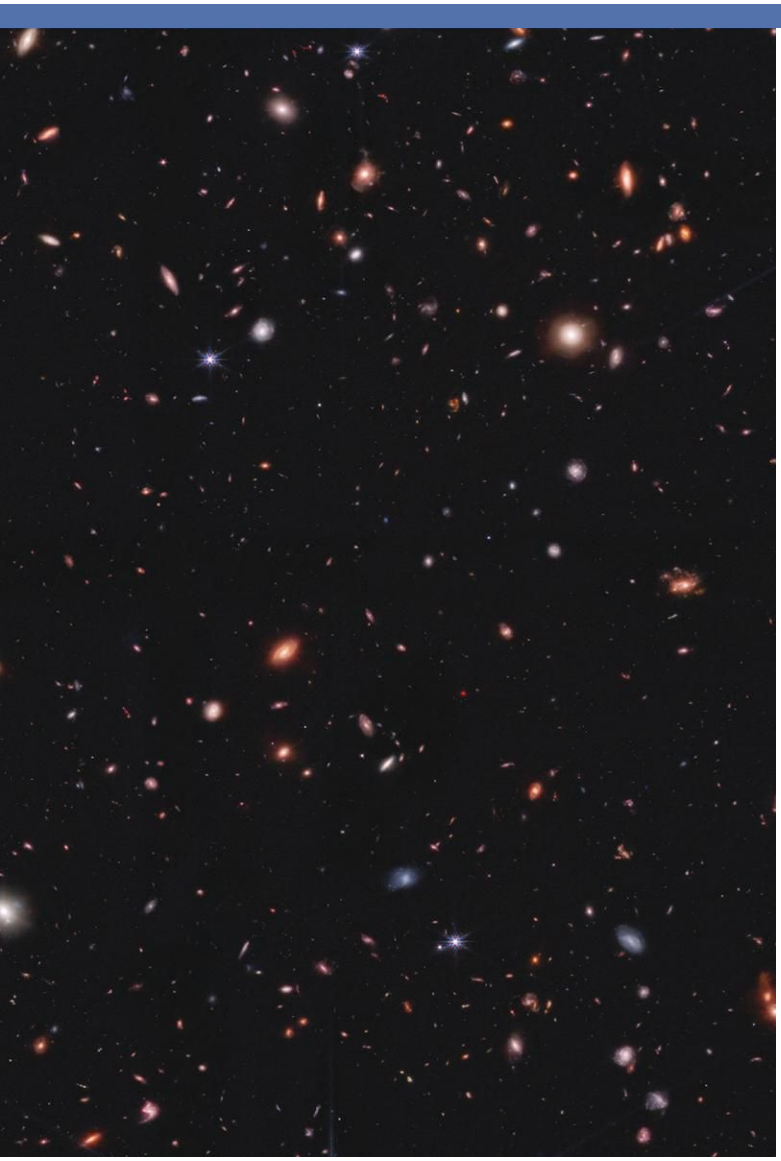
THE COSMOS MAY NOT BE BROKEN AFTER ALL. Soon after the James Webb Space Telescope (JWST) started its science mission in 2022, astronomers discovered a half-dozen galaxies near the universe's edge that appeared far more massive than anyone expected. (See "Too big, too soon" in the September 2023 issue.)

Prevailing theory held that the first galaxies were relatively small clouds of gas, stars, and dust that slowly grew into the majestic spirals and unassuming ellipticals that populate today's universe. But based on the amount of light these six galaxies emitted, researchers estimated that each weighed at least 10 billion solar masses and one seemed 10 times that size, or nearly the bulk of the Milky Way.

The observations implied that these galaxies — all existing within 1 billion years of the Big Bang — were converting nearly 100 percent of their gas into stars. Cosmologists

JWST finds that accreting black holes may explain why early galaxies appeared more massive than they truly are. BY RICHARD TALCOTT

GALAXIES?



couldn't figure out how this was possible, at least within the standard model of cosmology. But the astronomers who studied these galaxies, led by Ivo Labbé of the Swinburne University of Technology in Melbourne, Australia, stressed that their results were preliminary, and that future observations were needed to rule out other possibilities.

A FRESH LOOK

A new study brings one of those alternatives front and center. It finds that some early galaxies hold far less mass than they appeared to initially. In these objects, a significant portion of their light radiates from an accretion disk surrounding a centrally located supermassive black hole.

These black holes can boost a galaxy's output by 10 times or more. As the black hole pulls in surrounding material, an accretion disk forms. Friction within the disk heats the material to millions of degrees and produces copious amounts of light.

Katherine Chworowsky, a graduate student at the University of Texas at Austin, led a team that analyzed 118 massive galaxies — those weighing more than 10 billion solar masses — in the distant cosmos. "We are still seeing more galaxies than predicted [at these early times]," said Chworowsky in a press release, "although none of them are so massive that they 'break' the universe." The researchers reported their results in the September 2024 issue of *The Astronomical Journal*.

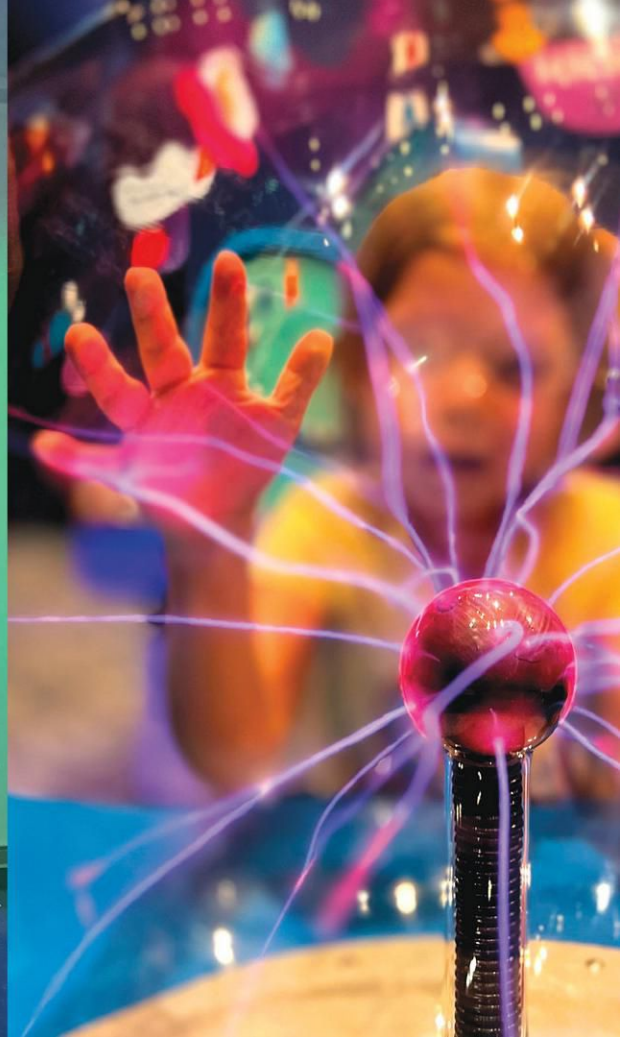
The accretion disks appear small and reddish on JWST images. And spectra reveal fast-moving hydrogen gas, a signature of accretion disks. When the team removed these objects from their analysis, the early galaxies that remained fell within theoretical predictions. "The bottom line is there is no crisis in terms of the standard model of cosmology," said co-author Steven Finkelstein, also of the University of Texas.

QUESTIONS REMAIN

The new results may have solved the biggest puzzle posed by the initial observations — that early galaxies appeared to be too massive — but cosmologists aren't out of the woods yet. Chworowsky's team also discovered roughly twice as many massive galaxies in their sample than the standard model predicts. She suggests that galaxies in the early universe may have been more efficient at turning gas into stars than those that exist today.

The idea isn't as strange as it may sound. Although stars in the nearby universe form at a snail's pace — the Milky Way creates only a few new stars every year — the higher densities and low abundance of elements heavier than helium at early cosmic times could well increase this rate significantly.

Contributing Editor **Richard Talcott** *wrote about JWST's observations of the super star cluster Westerlund 1 in the January issue.*



MARLEY FOUNDATION ASTRONOMY DISCOVERY CENTER

Lowell Observatory has expanded and improved its guests' experience by adding an immersive science center.

Light patterns
Atoms are like magicians—they make light appear and disappear.
Atoms absorb and emit different colors of light.
WONDERS REVEALED
The lines we see in light from distant worlds are like barcodes at the store. Both give us information.
HOW DOES IT WORK?
What is light?
Almost everything we know about the universe comes from light.

LEFT TO RIGHT: Enter the Spanier-Beckage Orbits Curiosity Zone, where children can learn and meet the alien mascots, Marzee and Pluie.
ALL IMAGES: LOWELL OBSERVATORY, UNLESS OTHERWISE STATED

The Orbits Curiosity Zone offers everyone opportunities to immerse themselves in the world of science.

The Joyce Marley Corrigan Stardust Lab is meant to teach people of all ages about stars and how elements of the universe are interconnected.

BY KEVIN SCHINDLER AND MADISON MOONEY

LAST NOVEMBER, LOWELL OBSERVATORY HERALDED a new era of public astronomy outreach with the opening of its Marley Foundation Astronomy Discovery Center (ADC) in Flagstaff, Arizona. The blend of exquisitely detailed planning and state-of-the art technology makes this a 40,000-square-foot (3,720 square meters) factory of awe and wonder for people of all ages. Combine this with the observatory's rich, 130-year heritage as a leading center of astronomical research and education, as well as Flagstaff's reputation as the world's first International Dark Sky City, and the new center is truly unique in the world.

The ADC is not merely an upgrade of the observatory's current Steele Visitor Center (SVC), but a completely new facility situated west of the SVC. This new facility came about in response to ever-increasing interest in the observatory's public programs, a trend that has been demonstrated throughout the history of the observatory and highlights its close connection to the heritage of astronomical research.

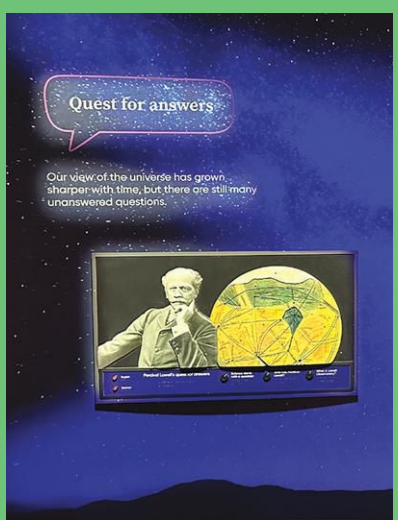
A legacy of codiscovery

American businessman and astronomer Percival Lowell founded his observatory in the frontier town of Flagstaff in 1894. He chose the site for its freedom from artificial light and smoke pollution, then the bane of skywatchers on the U.S. East Coast. He sought such a location in order to maximize his ability to explore the night sky in support of his desire to prove the existence of extraterrestrial life on Mars, as well as other astronomical interests.

But Lowell's interest in astronomy transcended research alone; he wanted to inform and inspire fellow astronomers as well as the general public. He published his scientific results in both traditional academic sources and more public-facing outlets.

Lowell promoted his concept of codiscovery by welcoming visitors to look through the observatory's telescopes on select evenings. Even after Lowell's passing in 1916, staff continued this tradition of public telescope viewing, sometimes coupled with a lecture or tour of the grounds. Clyde Tombaugh often took on these tasks after arriving at the

A plasma sphere shows off a strange form of matter. Though found throughout the cosmos, it is rare in our daily life on Earth.



Percival Lowell paved the way for Flagstaff to become one of America's centerpoints for astronomy and planetary science.

Within the Orbits Curiosity Zone, visitors can experiment with vapor to explore the same physics that affect larger clouds of gas and dust throughout the universe.

observatory in 1929 to help in the search for Lowell's hypothetical ninth planet.

A year later, Tombaugh's discovery of Pluto put the observatory and Flagstaff on the map. Visitation to the facility rapidly expanded. This interest ebbed and flowed through the years, all while the observatory lacked a formal visitor center. In the mid-1960s, the observatory moved its library from the old Rotunda to the Planetary Research Center (now known as the Hendricks Center for Planetary Studies), eventually allowing staff to convert the Rotunda into a visitor center and begin organizing public exhibits and events.

After Lowell's grandnephew, William Lowell Putnam III, took over the role of sole trustee in the late 1980s, he decided to significantly expand and formalize the observatory's public program. He envisioned a dedicated visitor facility and spearheaded the effort to build the SVC, along with a parking lot that would allow the observatory to triple its attendance — up to some 60,000 to 70,000 visitors per year.

In the ensuing two decades, the observatory expanded their resources for the public: more telescopes for public viewing, the return of the Pluto Discovery Telescope to its original dome, and increased staff and programs.

The research side of Lowell's operations expanded during this era as well, especially with breaking ground for the Lowell Discovery Telescope in 2005. This state-of-the-art telescope became Lowell's flagship research observatory, boasting a revolutionary instrument cube that allows for the simultaneous attachment of five instruments, making it one of the most versatile telescopes in the world.

However, these extra resources, combined with increased interest in astrotourism and general visitation to Flagstaff, meant the observatory began outgrowing its existing visitor center. Then, Pluto struck again, as it had in 1930: In 2015, the New Horizons spacecraft flew by the dwarf planet and offered the first up-close glimpses of this compelling world. The resulting unprecedented media attention sparked the interest of people of all ages, and soon more than 100,000 people flocked to the observatory each year.

A DIVE
Sponsored by
A STAR OF PEACE
Ibrahim Amiri's fascination with astronomy began at the age of 7 when he saw Comet Hale-Bopp in the sky above the refugee camp in Pakistan where he was born. "It changed my life," he says. Today, Ibrahim brings the wonders of the universe to people of all ages in his war-torn homeland of Afghanistan.
"DON'T HIDE YOUR STEM CURIOSITY, SHARE IT WITH YOUR COMMUNITY"
Malik Bossett is a graduate student in the Department of Astronomy and Astrophysics, University of California, Santa Cruz. He plans to become a professional astronomer and search for planets and life beyond Earth. Malik's interest in astronomy was sparked as a young boy when his father took him to the solar system exhibit at the California Academy of Sciences.
THE COLORS OF THE NIGHT

The world's premier public astronomy destination

The explosion in interest taxed the facilities and staff. On busy nights, visitors would circle the parking lot several times before eventually leaving after finding no place to park. At times, the lines for

RSE UNIVERSE
W. L. Gore & Associates
Astronomy
compels the soul to look upwards and leads us from
this world to another. – Plato, philosopher

The ADC's outdoor patio displays images of several cosmic objects, bringing the stars in the sky to the ground to guide visitors.

The Diverse Universe wall humanizes astronomy by showing numerous people who made their mark in history, hopefully inspiring children to pursue their dreams in science.

the telescopes were excessively long, and many visitors gave up trying to get into the packed gift shop.

With the mindset that the sky is not the limit but merely the starting point, Lowell Observatory's leadership, led by new Sole Trustee William Lowell Putnam IV and Executive Director Jeffrey Hall, decided it was time to again significantly expand the visitor experience. This meant not just offering more experiences for guests, but incorporating the most unique, state-of-the-art exhibits and programming possible as well. To achieve this, the observatory worked with community leaders throughout Arizona, as well as consultants who specialize in creating public science experiences around the world, to formulate the most inspiring yet achievable visitor experience.

The result would be a new visitor facility, parking area, and infrastructure that could accommodate many more visitors. Such a facility would take years of planning and fundraising to complete; therefore, leadership decided to first build a new telescope observing plaza that would allow crowds to spread out and minimize congestion at any one telescope.

The Giovale Open Deck Observatory opened Oct. 5, 2019, featuring a suite of six telescopes that allow guests to view celestial objects in several ways, from peering through eyepieces to viewing on large monitors.

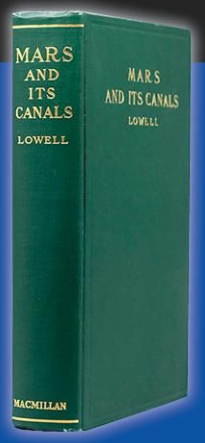
Then came the heavy planning for what is now known as the Marley Foundation Astronomy Discovery Center. For this facility, observatory leadership leaned on a growing body of evidence indicating that free-choice learning experiences at private science centers contribute more significantly to the public's scientific literacy than science coursework in high school and college. Particularly for children, experiences gained in such centers are major predictors for future science inquiry skills and academic achievement.

Community leaders and partners joined Lowell Observatory staff on June 26, 2019, to break ground on the 40,000-square-foot (3,720 square meters), three-story-high facility. However, as with any project of this scale, problems arose along the way. Less than a year after construction began, COVID and its resulting supply-chain issues threatened the ADC as the cost of materials skyrocketed, driving the price up a

MARS AND ITS CANALS

Percival Lowell gave rousing public lectures and wrote several popular books. He captured his perspective on the importance of sharing science with nonspecialists in his 1906 book, *Mars and Its Canals*.

In it he wrote: "To set forth science in a popular, that is, in a generally understandable, form is as obligatory as to present it in a more technical manner. If men are to benefit from it, it must be expressed to their comprehension. To do this should be feasible for him who is master of his subject and is both the best test of, and the best training to, that post. Especially vital is it that the exposition should be done at first hand; for to describe what a man has himself discovered comes as near as possible to making a reader the co-discoverer of it." — *K.S. and M.M.*



AMERICAN INSTITUTE OF PHYSICS

whopping 30 percent and increasing the final budget to $53.6 million.

Despite these challenges, the ADC opened on time, with the public getting first access Nov. 13, 2024, leading up to the grand opening event Nov. 16.

A stroll through the ADC

Martian Statues

Upon arriving at the ADC, guests are welcomed by three playful "martians" gathered around a sculpture of the Perseverance Mars rover, whose nickname Percy offers a coincidental connection to observatory founder Percival Lowell and his relentless quest to find life on Mars. The martians are portrayed as oversized microbes, highlighting that if life ever existed (or still exists) on Mars, it was likely microbial. The sculpture also presents a fantastic opportunity for group photos.

Prism Hall

The Prism Hall's stunning stained-glass skylight scatters rainbow light patterns across the floor and walls of the ADC's entryway. To the left of the entrance lies the Starry Skies Shop, while the Planet X Cafe is located to the right. Directly ahead, guests will find the front desk, where they can buy tickets, pick up maps, and ask questions about programs. Monitors behind the desk and hanging overhead display the day's schedule for showtimes, open houses, and telescope viewing sessions.

ADC built the Stardust Lab with the goal of teaching visitors that everything on Earth and in the solar system stems from the elements of the nebula the Sun was born in — all connected to the cosmos.

Planet X Cafe

Planet X Cafe, operated by the locally owned Jitters Lunchbox, offers a menu of soups, salads, hot and cold sandwiches, and beverages. It's open during afternoons and evenings, and, with seating for around 40 guests, provides a relaxing spot for them to enjoy a meal or snack between the observatory's many public astronomy events. Visitors can dine either outdoors on the patio, surrounded by the observatory's pine-covered landscape, or indoors by a cozy, sandstone-lined fireplace.

Starry Skies Shop

The Starry Skies Shop is the observatory's gift shop, offering visitors a variety of unique souvenirs to remember their time at Lowell. The selection includes T-shirts, educational STEM toys, stickers, water bottles, enamel pins, and more. New to the ADC collection are charming plush versions of the observatory's Curiosity Zone mascots, Marzee and Pluie.

Origins Gallery

The Origins Gallery serves as the central hub of the ADC, connecting visitors to

WELCOME TO
THE STARDUST LAB
You're part of an amazing story—the story of the universe!
"Everything in the universe has a rhythm, everything dances."
—Maya Angelou

all exhibit halls and attractions within the building. At the heart of this space is the Origins exhibit, an artistic representation of the universe's evolution from the Big Bang to the emergence of life on Earth. Suspended from the ceiling, the exhibit's centerpiece symbolizes the transformation of matter from its simplest post-Big Bang forms into the complex elements essential for life. Individually controlled lights along the structure create dynamic patterns, evoking a sense of motion. The landforms section of the exhibit features 3D surfaces enhanced with projections, showcasing the beauty and diversity of life on Earth.

Astronomy Gallery: Stardust Lab

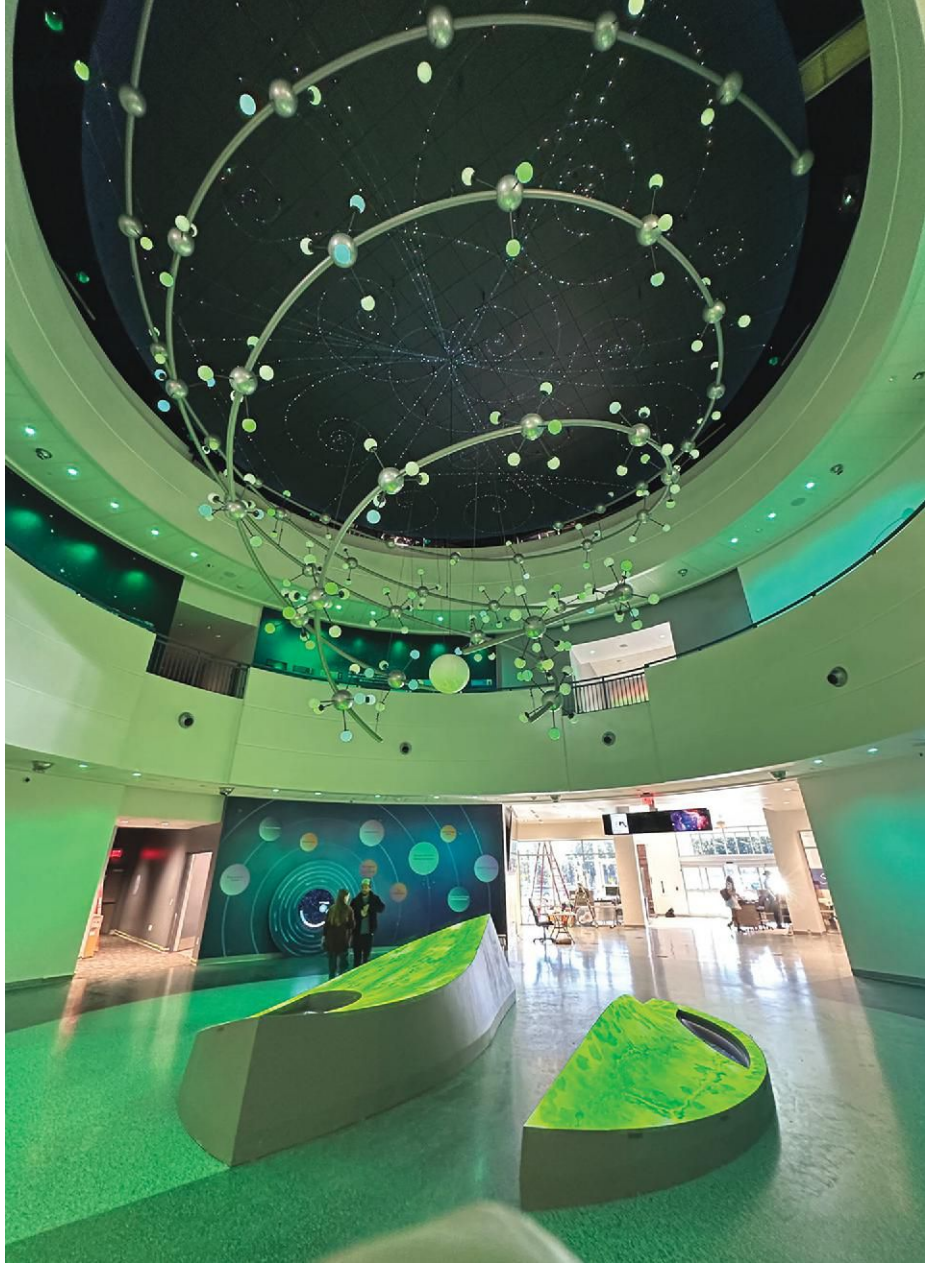
The Stardust Lab offers unique, thought-provoking exhibits around the central theme that we are all made of stardust. It is designed to encourage visitors to reflect on their place in the universe while exploring the many planets and solar systems astronomers are discovering in the Milky Way. All exhibits in this hall have integrated audio, touch, and braille features to ensure that they're accessible. One highlight is an interactive video screen with body-tracking technology, projecting "stardust" silhouettes of visitors, who can select a part of their silhouette and trace its origins back to the Big Bang. Guests can also send messages into the cosmos through a digital interface, as well as read messages left by others. And one exhibit engages the senses by letting visitors experience the scents of the universe!

Orbits Curiosity Zone

The Orbits Curiosity Zone is an interactive exhibit hall for budding scientists, marking Northern Arizona's first hands-on science exhibit aimed at engaging children. Vibrant displays blend fun with learning as kids explore the wonders of the cosmos, led by the charming alien mascots Marzee and Pluie. Interactive features like the Rocket Launcher, where kids can custom-build and launch their own rockets, are designed to deliver an exciting learning experience packed with discovery and fun.

Lowell Universe Theater

This state-of-the-art theater is an attraction in its own right, employing features of a planetarium but customized to continue the observatory's emphasis on live presenters. Its 25-foot-tall (7.6 m), 160-degree wraparound 16K LED screen delivers a fully immersive experience. With seating for up to 180 guests, the space features a stage where educators and actors lead interactive programs, staying true to Lowell's hands-on approach. The Universe Theater transports visitors across the cosmos, from the heart of ancient meteor impacts on Earth to the distant surfaces of Mars, Pluto, and beyond. Recorded films, such as *This Is Lowell*, are also shown in the theater at scheduled times throughout the day.



In the enchanting Origins Gallery, guests can view the abstract centerpiece showing how the Big Bang is linked to today's complex structures, as well as explore other exhibits.

Great Planetary Hall

The walls of the Great Planetary Hall feature striking astrophotography prints and astronomy-inspired paintings. The room spills out onto a patio, making this space ideal for events such as private parties or member gatherings.

Diverse Universe Wall

This space is designed to inspire children to see themselves as future scientists by showing the human side of science around the world. It explores scientists' unique life stories, the challenges they have overcome, and more. Just as no two planets, stars, or galaxies are alike, neither are the people who study them.

Kevin Schindler *is historian at the Lowell Observatory.* **Madison Mooney** *is a specialist in content writing and marketing.*

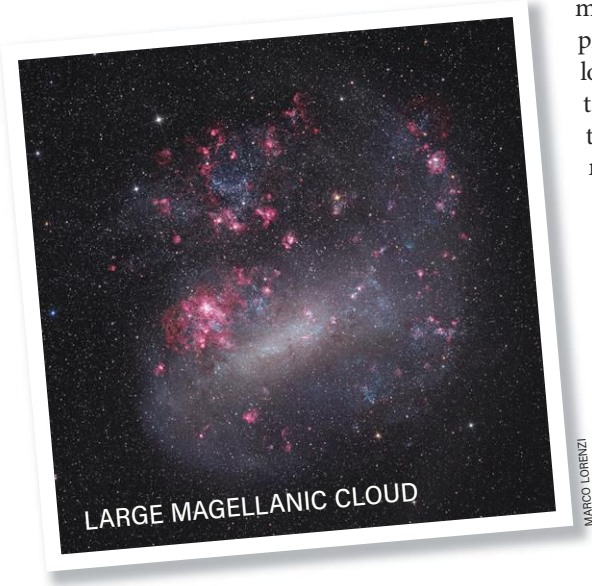
EXPLORE THE

BRIGHTEST DEEP-SKY OBJECTS

THE PLEIADES (M45)

It's surprising how few of these amateur astronomers have seen. BY MICHAEL E. BAKICH

YOU KNOW, AFTER DECADES of pointing optics toward the sky, I consider myself a knowledgeable observer. But while researching the Pleiades a few months back, I was surprised to learn that it wasn't the brightest star cluster. And there were other surprises when I started comparing overall brightnesses of deep-sky objects.


LARGE MAGELLANIC CLOUD

MARCO LORENZI

For instance, you might think some easy winners would be galaxies, housing billions of stars, but when I started ranking objects, only two galaxies made the Top 25; most of the targets I've listed here are either open clusters, stellar associations (looser, poorly populated open clusters), or asterisms.

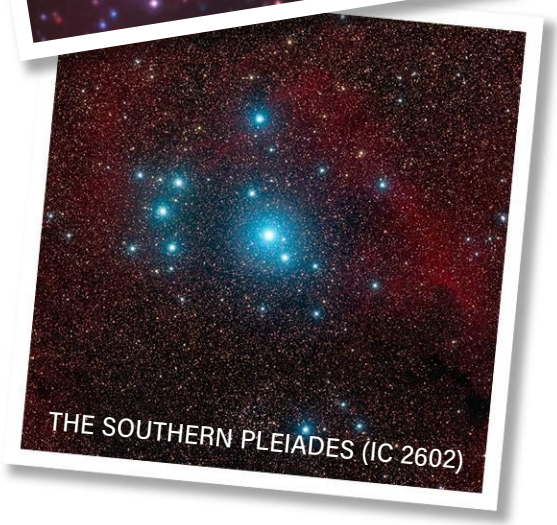
While you may have looked near many of these targets before, you probably didn't *really* observe them, looking past the forest for the fainter trees. Well, here's your chance to take a step back and take in the most light the night sky has to offer.

Top of the heap

You may have guessed that the brightest deep-sky object is the first galaxy on our list, the **Large Magellanic Cloud**. Straddling the border between the constellations Dorado and Mensa, it glows at a worthy magnitude 0.1. And it's huge: It covers an area greater than 9° by 11°, or 400 times that of the Full Moon. Visible just south of latitude 20° north, the Large Magellanic Cloud is best seen in the Southern Hemisphere summer (that is, December through February).

Second on the list is the open cluster **Hyades** and the neighboring bright star Aldebaran (Alpha [α] Tauri). Together, they form a V-shaped group that marks the head of Taurus the Bull. Although Aldebaran is counted as part of the Hyades, giving that group a worthy magnitude 0.5, it's not part of the star cluster — it actually lies nearly 90 light-years closer to us.

The third-brightest deep-sky object, glowing at magnitude 0.6, is Collinder 70, an open cluster of 100 or so hot young stars. You may know it by the more famous name of its three brightest members: **Orion's Belt**. The Belt is probably tied with the Big Dipper as the most well-known asterism in the night sky. But



TOP TO BOTTOM: WARREN A. KELLER; TONY HALLAS; MARCO LORENZI

through even modest binoculars, the Belt looks to be embroidered with a slew of fainter, still bright companions.

Tied for third place on our list — also at magnitude 0.6 — is **Collinder 173**, a loose (6°-wide) open cluster on the border between Puppis and Vela. It lies about 1,400 light-years away. Such a bright cluster should be easy to find, but it's tough to identify the members. Look roughly 10° north-northwest of Alsephina (Delta [δ] Velorum), and use 7x50 binoculars to frame it best.

Coming in at No. 5 with a magnitude of 1.0 is the **Upper Scorpius association** — an association rather than an official open cluster. Also called the Antares Cluster, this 8°-wide group surrounds the star Antares (Alpha Scorpii). Even low-power, wide-field 7×50 binoculars can't take in the entire group, so you'll have to scan around. You've probably seen these stars — the four front stars of Scorpius (β, δ, π, ρ) plus a few others — lots of times, but perhaps never knew that they were an association.

No. 6 on our list is the **Alpha Persei Cluster**, an open cluster named after its brightest member: magnitude 1.8 Mirfak (Alpha Persei). With a total magnitude of 1.2 and a diameter of 6°, it's easy to find and just small enough to frame through 7x50 binoculars.

One of the more famous objects on this list, coming in seventh place with a magnitude of 1.6, is the **Pleiades** (M45). In ancient times, this star pattern was so highly regarded that many Greek philosophers considered it a separate constellation. Often called the Seven Sisters, a reference to a Greek myth, most sharp-eyed observers can only spot six stars. High-quality binoculars will raise that number to 50.

The eighth-brightest deep-sky object is the **Coma Star Cluster** (Melotte 111), an open cluster that lies some 280 light-years away. Although its combined magnitude is 1.8, that brightness is spread across an area 4½° wide. The cluster contains fewer than 100 members, and only a dozen or so are bright enough to see without optics. So, use binoculars.

The **Southern Pleiades** (IC 2602), a gorgeous open cluster that surrounds the star Theta (θ) Carinae, comes in ninth on our list. It glows at magnitude 1.9 and spans nearly 1°. Binoculars that magnify 10x or more do a good job revealing this cluster, but if you have an eyepiece in your telescope that has a field of view of 1° or more, you're in for a real treat.

Second class

The 10th object on our list is the first to fall into the 2nd-magnitude class. It's the **Pi Puppis Cluster** (Collinder 135), which is centered around the magnitude 2.7 star Ahadi (Pi [π] Puppis). This star sits alone about 7° east of the midpoint of a line between the sky's two brightest stars, Sirius (Alpha Canis Majoris) and Canopus (Alpha Carinae). The cluster has a total magnitude of 2.1, but Pi is the standout for two reasons. First, it's the brightest star, and second, it's a red supergiant. All the other stars in the field of view are blue.

The **Omicron Velorum Cluster** (IC 2391) registers at magnitude 2.5, and is tied for 11th on our list. This isn't a small object, measuring just less than a degree in diameter. That means its area is more than twice that of the Full Moon. The best views through any scope will come when you use an eyepiece that gives a 1° field of view.

The next object is one I'm sure you've seen hundreds of times but may not have known it was an open cluster. The **Lost Jewel of Orion**, otherwise known as NGC 1980, glows at magnitude 2.5. It's centered around the magnitude 2.8 star Iota (ι) Orionis, and is part of the Hunter's Sword. It lies just south of the Orion Nebula (M42).

Yet another pair ties for lucky 13, with first up the open cluster **Collinder 121** in Canis Major. You'll find it less than ½° south of Omicron[1] (o[1]) Canis Majoris. It glows nicely at magnitude 2.6 and has a diameter of 30'. It lies some 3,500 light-years away, but there's another, more widely spread, group of stars just 2,000 light-years distant, between Collinder 121 and us. No worries, though. The closer stars will simply appear as field stars through your eyepiece.

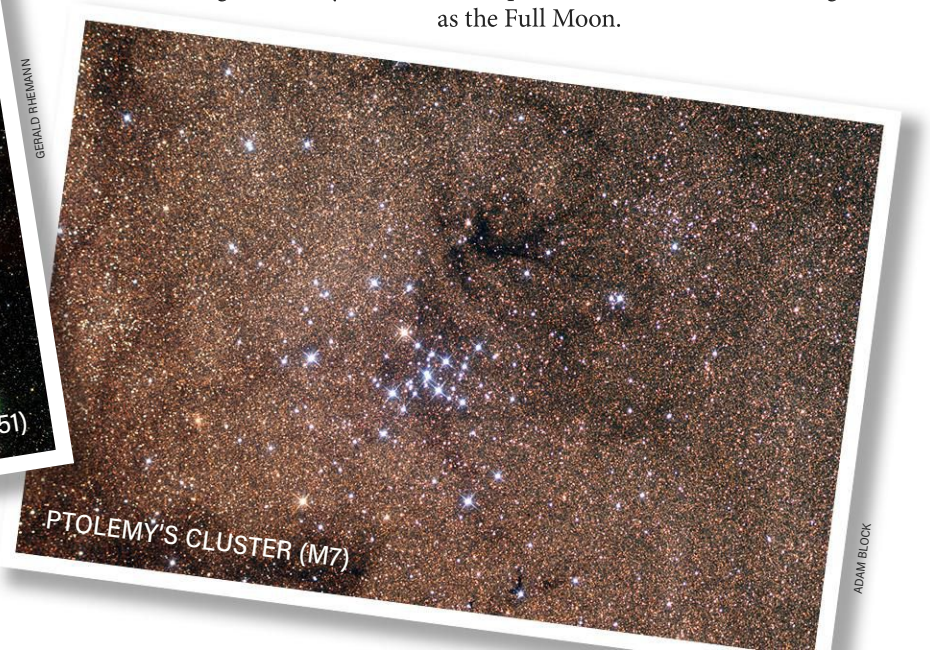
Tied with Col 121 is the open cluster **NGC 6231** in Scorpius. Often called the Baby Scorpion Cluster, it also glows at magnitude 2.6 and spans 15'. Along with Zeta (ζ) and Mu (μ) Scorpii, it forms an asterism British astronomer Sir John Herschel called the False Comet. He named it this for two reasons: 1) The group looks like a comet; and 2) Herschel, who had traveled on a ship to South Africa to view the southern sky, landed at False Bay.

The other galaxy on our list, and the 15th-brightest deep-sky object, is the **Small Magellanic Cloud**, which lies mainly in Tucana with a small part in Hydrus. Its combined brightness equates to a 2.7 magnitude star. It lies some 200,000 light-years away, but still covers an area of sky a bit greater than 5° by 3°. That's a space more than 70 times as large as the Full Moon.

IN THE 1990S, ASTRONOMERS DISCOVERED THAT THE STINGING SCORPION CLUSTER WAS A COMBINATION OF TWO OPEN CLUSTERS (NOW KNOWN AS NGC 2451A AND NGC 2451B) THAT ALIGN FROM OUR POINT OF VIEW.

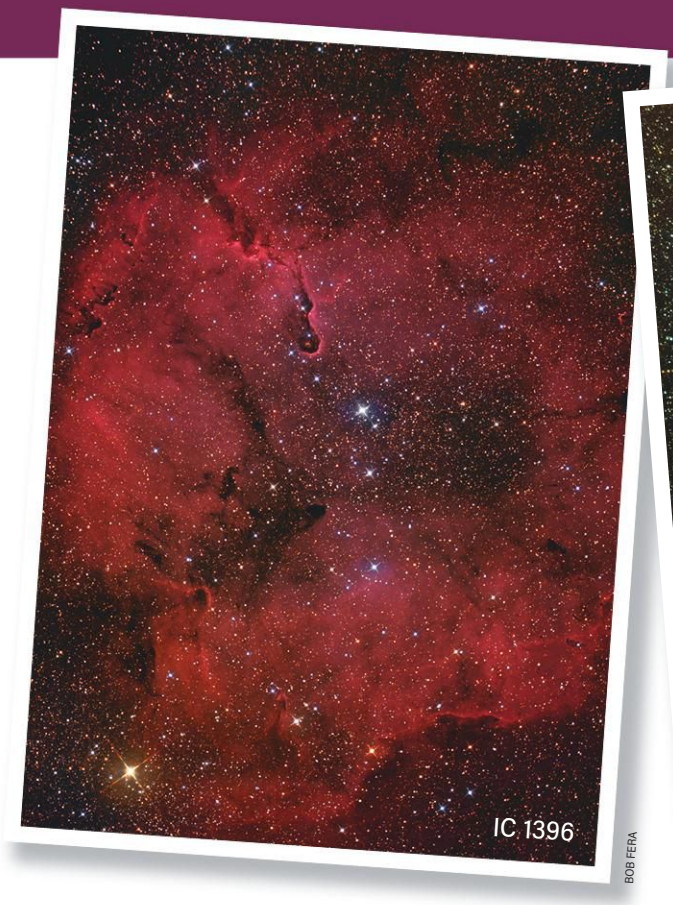
THE STINGING SCORPION CLUSTER (NGC 2451)

GERALD RHEMANN



PTOLEMY'S CLUSTER (M7)

ADAM BLOCK



BOB FERA

DARRYN LAVERY

The **Lambda Orionis Cluster** in Orion makes our list at number 16. It's easy to find because its brightest member is Meissa (Lambda [λ] Orionis), the star that marks Orion's head. The cluster glows at magnitude 2.8 and spans a bit less than 1°.

Tied for 16th place, also at magnitude 2.8, is open cluster **NGC 2451** in Puppis, sometimes called the Stinging Scorpion Cluster. In the 1990s, astronomers discovered that this object was a combination of two unrelated open clusters (now known as NGC 2451A and NGC 2451B) that align from our point of view.

Bottom of the top

Eighteenth on our list is open cluster **Collinder 65** in Orion. In fact, it lies about as far north in that constellation as you can go, right on the border with Taurus. It glows at magnitude 3.0, and it's large: It boasts a diameter of 3½°. Wide-field binoculars will show the cluster best.

Tied for 18th place is the **Firefly Party Cluster** (NGC 3532) in Carina. Point a 4-inch scope at this beauty, and you'll understand how it got its whimsical name. Look for it roughly 4.7° south-southwest of 4th-magnitude Pi Centaurus. Its 3rd magnitude brightness is spread out over nearly a 1° diameter, so even though you'll see it as a fuzzy patch without optical aid, a telescope will bring out its best features.

Also tied for 18th place is **Melotte 186**, a loose open cluster in Ophiuchus. And when I say loose, I mean it. Although the combined brightness of its stars equals magnitude 3.0, the diameter of this group is a whopping 4°. Use binoculars or scan around with the lowest-power eyepiece in your telescope to view the whole group.

You've probably seen No. 21 on our list. It's the **Beehive Cluster**, also known as the Praesepe, M44, NGC 2632, and more. This open cluster lies in the center of Cancer the Crab. Sharp-eyed observers have no problem seeing M44 with naked eyes, even if there's some scattered moonlight. It glows at magnitude 3.1 and has a width of more than three Full Moons.

The 22nd object lies near the bottom of the figure of Scorpius. It's **Ptolemy's Cluster** (M7), and is the most southerly Messier object. This open cluster is an easy naked-eye catch, glowing at magnitude 3.3, even though it lies centered within the Milky Way.

Collinder 140, an open cluster in Canis Major, shines 23rd on our list. It glows at magnitude 3.5 and spans 42′. To find it, look 3° due south of Aludra (Eta [η] Canis Majoris). Through an 8-inch scope at low power you should be able to count some three dozen member stars.

Sharing the 23rd slot is **Trumpler 37**, an open cluster in Cepheus. Longtime amateur astronomers, especially astroimagers, recognize this as the cluster in the heart of the Elephant Trunk Nebula (IC 1396). An 8-inch scope will reveal roughly 50 member stars.

The 25th and final object on our list is **Collinder 132**, an open cluster in Canis Major. To find it, look not quite 3° southwest of Aludra. It glows at magnitude 3.6 and spreads out over an area 1½° across.

OK, I lied. Collinder 132 isn't the last object because another group of stars is tied with it in brightness: the **Coathanger**, an asterism in Vulpecula. This object carries a variety of names, including Al Sufi's Cluster, Brocchi's Cluster, and Collinder 399. Although it's a loose glow to naked eyes, 7-power or greater binoculars show it as a 1¼° line of stars with a separate curve on the southern side, giving it the appearance of a coathanger.

And there you have it. Next time you step out into the darkness, take a minute to appreciate these not-so-hidden gems, and bask in all their glorious light.

Michael Bakich *is an associate editor of* Astronomy *who took years to see and identify all these objects.*

WE TEST

Starfield Optics'

This refractor produces excellent results with an eyepiece or a camera.

BY PHIL HARRINGTON

ONE OF THE MOST competitive segments in the amateur telescope marketplace these days spans 3- to 5-inch apochromatic refractors. Once considered telescopes for the well-to-do, these instruments are now affordable to many backyard stargazers. And one of the newest companies to enter this market segment is Starfield Optics from Caledon, Ontario, a suburb of Toronto.

Since opening its doors in 2017, Starfield Optics has produced amateur equipment geared largely toward astroimaging. Notably, the Géar line of imaging apochromatic refractors, ranging from a 2.4-inch f/5 to the 4.5-inch f/7 model reviewed here, have attracted a lot of attention in North America.

Recently, I had an opportunity to put their flagship, the Starfield Géar 115 Triplet APO, through its paces.

The author captured this image of the gibbous Moon through the Starfield refractor. PHIL HARRINGTON

First impressions

The telescope arrived safely directly from the manufacturer nestled in a foam-lined case inside a thick cardboard box. As soon as I unzipped the case and pulled out the optical tube assembly, I could tell that this was a well-built instrument.

The tube itself is made from high-quality aluminum, which delivers a solid feel while keeping the weight manageable. The tube measures approximately 28 inches (710 millimeters) long with the extendable dew shield stowed, and 35 inches (890 mm) when the shield is extended. The tube assembly weighs 15 pounds (6.8 kilograms), light enough to carry to remote locations.

The heart of the Géar 115mm is its triplet apochromatic objective lens, which significantly reduces chromatic aberration (the color fringing around bright objects). The result is sharp images with excellent color fidelity. The lenses are fully multicoated, which enhances light transmission and minimizes internal reflections. Staring through the objective and into the aluminum tube shows the interior is fully blackened. Four internal baffles minimize stray light from intruding into the optical path.

Putting it to the test

Each Géar 115mm comes with a comprehensive optical test report to objectively demonstrate the quality of its objective lens. The scope's test report for this review showed that the objective had a low peak-to-valley wavefront error of 0.143 wave. In the world of telescope optics, 0.25 wave is considered "diffraction-limited" performance (when a telescope has reached the theoretical maximum sharpness and clarity that is possible for its aperture).

Another measure for optical excellence is the Strehl ratio. A Strehl ratio of 1.0 is considered optical perfection. Our test Géar 115mm came in with an impressive Strehl ratio of 0.972.

Although I couldn't validate the report's values, I can confirm that the optics were excellent. When I performed a test by viewing stars at high magnification, the stars showed textbook diffraction patterns. Further, when I shifted the view slightly to either side of focus, I couldn't detect any sign of astigmatism or chromatic aberration.

new scope

Starfield Optics' Géar 115mm Triplet is as beautiful to look through as it is to look at.
STARFIELD OPTICS

Besides exceptional optics, this refractor also includes mechanical features valued by visual observers and imagers. The dual-speed 2.5-inch rack-and-pinion focuser, with its included adapters, accepts both 1¼" and 2" eyepieces and star diagonals. The focuser's movement was smooth and responsive with no backlash. Its 10:1 reduction gearing makes it easy to achieve focus. The focuser is also fully rotatable and can be outfitted with optional motor control.

The Géar 115mm includes nicely machined CNC heavy-duty tube rings and a Vixen-style dovetail bar for easy mounting on a wide range of equatorial and alt-azimuth mounts. A second beam across the top of the rings serves as a carrying handle. It also has five tapped holes. The center hole has a ¼"-20 thread, while the others are M6 metric threaded. Additionally, the telescope's focuser incorporates a standard Synta-style finder scope mounting shoe.

I set up the Géar 115mm on my German equatorial mount and attached my own finder scope. All tests were done from my suburban backyard.

Time to play

The first object I looked at was the gibbous Moon. Our satellite's limb is a telling sight through refractors. When using lesser-quality instruments, the lunar edge is rimmed with yellow and purple chromatic aberration, whereas a true apochromatic instrument keeps it gray. And that's exactly what I saw through the Géar 115mm, even with magnifications above 200x.

The two stars of Albireo (Beta [β] Cygni), my favorite double star, displayed a striking golden and azure vibrance. The Géar 115mm also beautifully displayed the quadruple Trapezium system in the Orion Nebula (M42). The view took my breath away as I stared at the four blue-white stellar sapphires twinkling amidst the surrounding wisps of nebulosity. The belts of Jupiter's atmosphere also showed themselves nicely, as did the Great Red Spot. Even Saturn's clouds, which are far more subtle, hinted at delicate variations in color.

The 805-millimeter focal length of the Géar 115mm also makes this a great telescope for guided imaging. With that in mind, the company included a Camera Angle Adjuster. It lets the user rotate their camera while not affecting focus, useful when you want to frame your image a certain way.

For those striving for image perfection, a flattener is a must. For this, Starfield Optics sells an optional 0.8x adjustable reducer and 1.0x flattener separately. The former flattens the field to produce pinpoint star images to the edge, while also reducing the focal ratio to f/5.6. The flattener also creates pinpoint stars, but maintains the original focal length and focal ratio. With or without the 1.0x flattener, the scopes's actual field of view at prime focus measures 2.6° x 1.7° on a full-frame camera sensor. Adding the 0.8x adjustable reducer expands the field to 3.2° x 2.2°.

A scope you'll be proud of

The Starfield Optics Géar 115mm triplet APO refractor offers an impressive combination of optical performance, build quality, and value. Though a quality mount and other accessories are required, its value remains outstanding.

This telescope suits both experienced astronomers and those developing their skills. Use it for casual viewing, and then branch into photography if you wish. It delivers tack-sharp images of the rugged lunar surface, crisp views of the planets, and is great for deep-sky targets. In every way, its performance is comparable to more expensive models. I highly recommend the Starfield Optics Géar 115mm triplet APO refractor to anyone in the market for a high-quality refractor that promises years of happy stargazing.

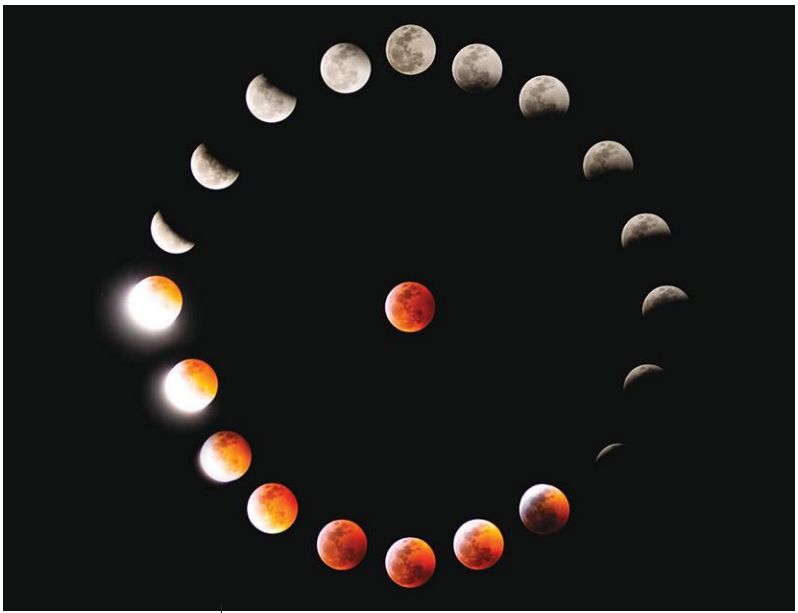
PRODUCT INFORMATION

Starfield Géar 115MM F/7 Triplet
Type: Apochromatic refractor
Aperture: 4.5 inches
Focal ratio: f/7
Focal length: 805mm
Focuser: 2.5" two-speed rack-and-pinion
Length: 28 inches (71 cm) with dew shield retracted
Weight: 15 pounds (6.8 kg)
Price: $2,100
Contact: Starfield Optics
670 Hardwick Road, Unit 5
Bolton, Ontario L7E5R5
Canada
905.487.6363
www.starfieldoptics.com

Phil Harrington *is a contributing editor of* Astronomy *who's happiest when outside at night with a high-quality telescope.*

Maximizing your lunar eclipse

You don't need special equipment, but you should plan ahead.



ABOVE: The author captured the phases of a lunar eclipse with a Nikon D5300 and Nikon 70-300mm lens at 300mm, f/5.6, on Jan. 20, 2019.

RIGHT: On the same night, an eight-second exposure with the same camera and lens revealed totality.
MOLLY WAKELING

BY MOLLY WAKELING
Molly is an avid astrophotographer active in STEM outreach. She has a Ph.D. in nuclear engineering.

During the night of March 13, most of North and South America will be treated to a total lunar eclipse, an event popularly referred to as a Blood Moon. The event is aptly named — the Moon is cast in a dark red, brown, or orange color during totality, giving it an eerie appearance in the night sky.

A lunar eclipse occurs when the Moon lies directly behind Earth from the Sun, an arrangement that occurs two or three times per year. Any given location on Earth is graced with a total lunar eclipse every 2.5 years on average. One might think that this should occur every month at Full Moon, but the Moon's orbital plane is not exactly in line with the Earth's plane around the Sun, so alignments occur less frequently. When the Moon only passes through the edges of the shadow cast by the Earth, we experience a penumbral eclipse, in which the Moon will darken almost imperceptibly.

The Moon's red color is due to how different colors of light scatter in Earth's atmosphere — bluer wavelengths scatter more than redder wavelengths, so more red light is refracted onto the lunar surface. How red and dark the Moon appears depends on the amount of dust and aerosols in Earth's atmosphere at the time.

For this month's eclipse, we will enjoy 1 hour 5 minutes of totality.

Lunar eclipses in the months and years following major volcanic eruptions are often dark due to the volcanic ash lofted into the atmosphere.

Unlike solar eclipses, where totality only lasts a few minutes, the darkest phase of lunar eclipses can last for more than an hour. For this month's eclipse, we will enjoy 1 hour 5 minutes of totality. This gives skywatchers plenty of time to observe and take photos. During the partial phase, bites are taken out of the Moon as it slips into Earth's shadow, going through all its phases in only an hour. During totality, the Moon appears as though a colored velvet blanket was laid on it, a beautiful and haunting sight against the black night sky. Binoculars or a telescope of any size can make the experience even more special.

For the shutterbugs among us, a DSLR on a tripod with a cable release will achieve the best images, although you can try with a smartphone as well. Depending on how dark the Moon is during totality, exposures of several seconds may be required. I often use a 70-300mm zoom lens atop a sky-tracking device such as a Vixen Polarie or Sky-Watcher Star Adventurer, but you can also adjust the camera's position on a tripod manually as the Moon moves across the sky and keep the exposure times short enough to avoid streaking.

Make sure you have a clear view of the Moon ahead of time using the PhotoPills app or a planetarium app such as SkySafari. You will have plenty of time during the eclipse to find the right ISO, f-stop, and exposure settings, so take a variety of test shots to make sure you get the ones you want. You don't need an f/1.4 lens to take great lunar eclipse photos; in fact, you may want to stop down your lens a bit to improve the appearance of background stars and keep from oversaturating during the partial phase. Taking photos throughout the eclipse and composing a final image that showcases all the phases is a fun way to share it with your friends who are clouded out. I recommend shooting in RAW so you can more easily modify the images later. Use "Live View" if your camera has it to bring the Moon into focus, and then tape down the focuser and zoom so they don't move during the eclipse.

Lunar eclipses are absolutely worth staying up late for — they may not have the awe and drama of a solar eclipse, but the velvety red button in the sky is hard to tear your eyes from. Take plenty of photos with your DSLR or smartphone, or just sit back and enjoy the spectacle with binoculars or just your eyes.

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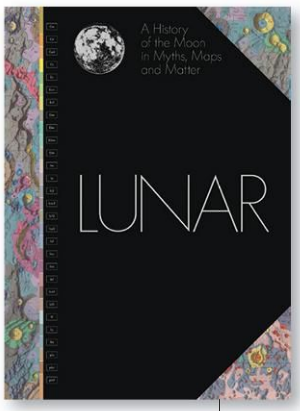

To the Moon

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Chicago, IL

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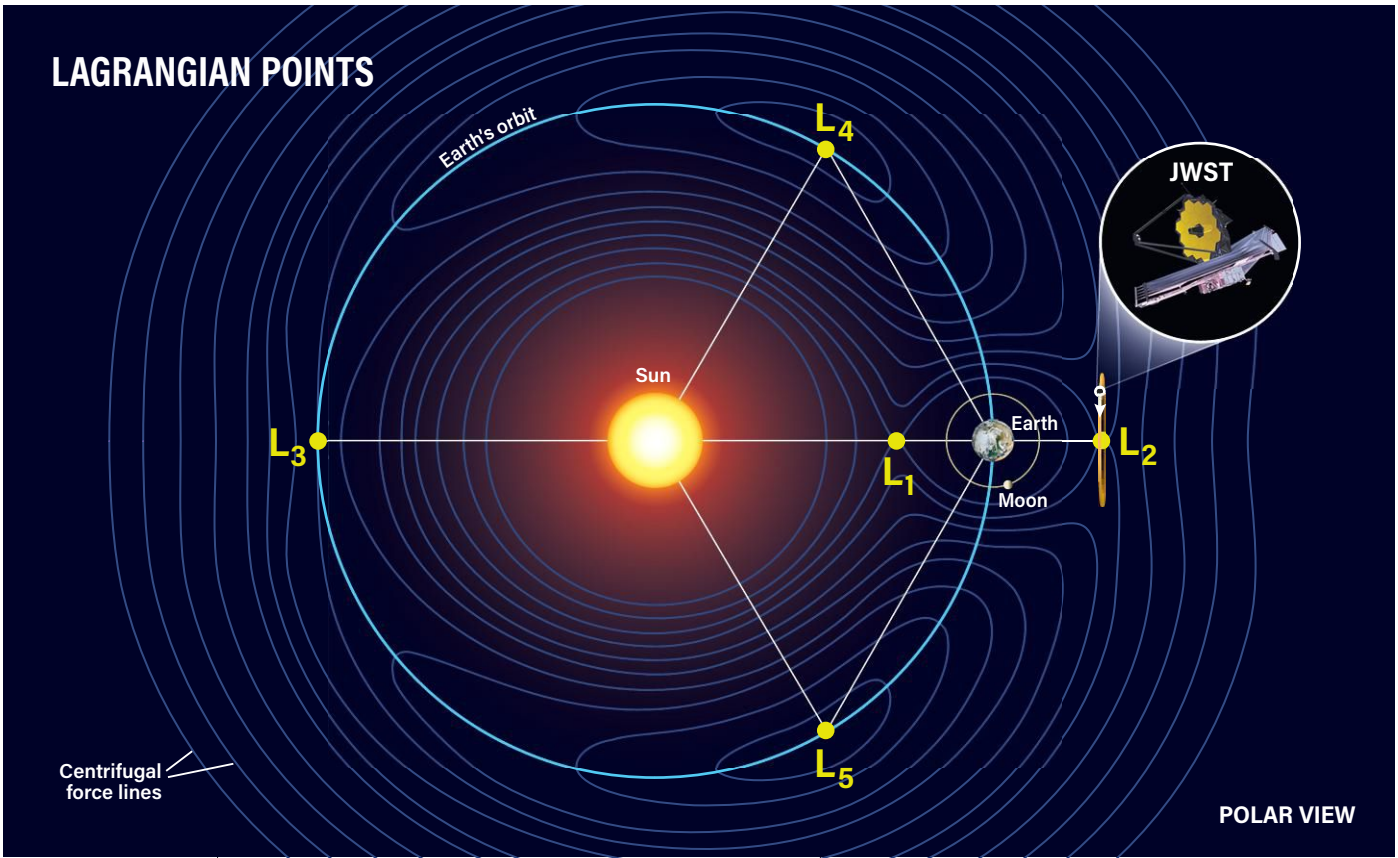


This illustration shows the location of the five Lagrangian points in the Earth-Sun system. Several spacecraft, including the James Webb Space Telescope (JWST), have orbits around L_2 because of its relative stability.
ASTRONOMY: ROEN KELLY; JWST: NASA

Lagrangian points

Q | WHAT ARE LAGRANGIAN POINTS?

Dean Treadway
Jesup, Georgia

A | The Lagrangian equilibrium stability points, or L points, are the five places where the combined gravitational forces of two bodies produce regions of gravitational balance. These are little pockets where other bodies can, in theory, remain orbiting in place without expending much energy.

Three of these L points, L_1, L_2 and L_3, are along the line connecting the orbiting body and its parent body: L_1 is located between them, at a point closer to the orbiter. L_2 is on the far side of the orbiter relative to the parent, and L_3 is on the far side of the parent relative to the orbiter.

The other two, L_4 and L_5, move along the path of the orbiting body, 60° ahead of and 60° behind the orbiter. The L_4 and L_5 points could each mark the apex of an equilateral triangle, with the parent and orbiter marking the other two points.

In his 1772 paper "Essai sur le Problème des Trois Corps" ("Essay on the Three-Body Problem"), Italian-French mathematician Joseph-Louis Lagrange mathematically determined that such stable points could exist within an orbiting system. At the time, these points were merely theoretical constructs.

In 1906, however, astronomer Max Wolf at the Königstuhl Observatory in Heidelberg, Germany, discovered the asteroid 588 Achilles at the L_4 point in Jupiter's orbit. Within the next year, two other asteroids were found at Sun-Jupiter L points: The asteroid 624 Hektor was observed at L_4, and 617 Patroclus was discovered at Jupiter's L_5. Soon thereafter, the prolific asteroid-discoverer Johann Palisa suggested that asteroids at Jupiter's L_4 and L_5 points be named for heroes from the Trojan War — the asteroids at L_4 for Greek figures and those at L_5 for Trojans. (Despite this convention's adoption, this is not true of the names for all 4,601 asteroids now known to exist at L_4, nor the 2,439 at L_5. Additionally, by this convention, Hektor and Patroclus are in the wrong "camps," and so are sometimes referred to as "spies.")

Today, all bodies located at the L_4 or L_5 points of any orbiting body are known as Trojans. Astronomers have

so far only found two Earth-Sun Trojans, 2010 TK_7 and 2020 XL_5, both of which are located at L_4.

Note that the L_1, L_2, and L_3 points are not stable over the long term. L_4 and L_5 are stable provided that the mass ratio between the parent and orbiting bodies exceeds 24.96, a mass ratio that certainly holds for every planet-Sun pair in our solar system. Although the other points are less stable, spacecraft have been deployed to them. For instance, the Solar Heliospheric Observatory (SOHO) satellite is currently in a halo orbit around Earth's L_1 point, located 932,000 miles (1.5 million kilometers) from Earth, in the direction of the Sun. And, of course, NASA's James Webb Space Telescope and the European Space Agency's Gaia probe are currently in orbit around L_2, also 932,000 miles (1.5 million km) from Earth, but on the far side of Earth relative to the Sun. As L_1 and L_2 are stable only over the short term — up to about 23 days — these spacecraft have to undergo periodic course and altitude corrections. All the same, these L points are prime locations for spacecraft, as they don't need to expend great quantities of fuel to maintain their positions there.

No space agency has bothered to send any craft to L_3 and there are no natural bodies around that point. The popular science-fiction convention that a secret planet lurks there seems highly unlikely because L_3 is unstable, so an object as massive as a planet would not be able to remain there for long.

Edward Herrick-Gleason
Staff Member, Southworth Planetarium, University of Southern Maine, Portland, Maine

YOU WOULD WEIGH ROUGHLY ONE-SIXTH YOUR EARTH WEIGHT ON THE MOON.

Q | IF YOU WEIGH A CERTAIN AMOUNT ON EARTH, HOW MUCH LESS OR MORE WOULD YOU WEIGH ON THE MOON?

Makayla
Arkansas

A | The short answer is that you would weigh roughly one-sixth your Earth weight on the Moon. So if your bathroom scale reads 180 pounds (81.6 kilograms) on Earth, it would read 30 pounds (13.6 kg) on the Moon. Though actually, your mass — expressed in kilograms — never changes, and your scale (built only for use on Earth) would be lying to you in metric. More on that in a moment.

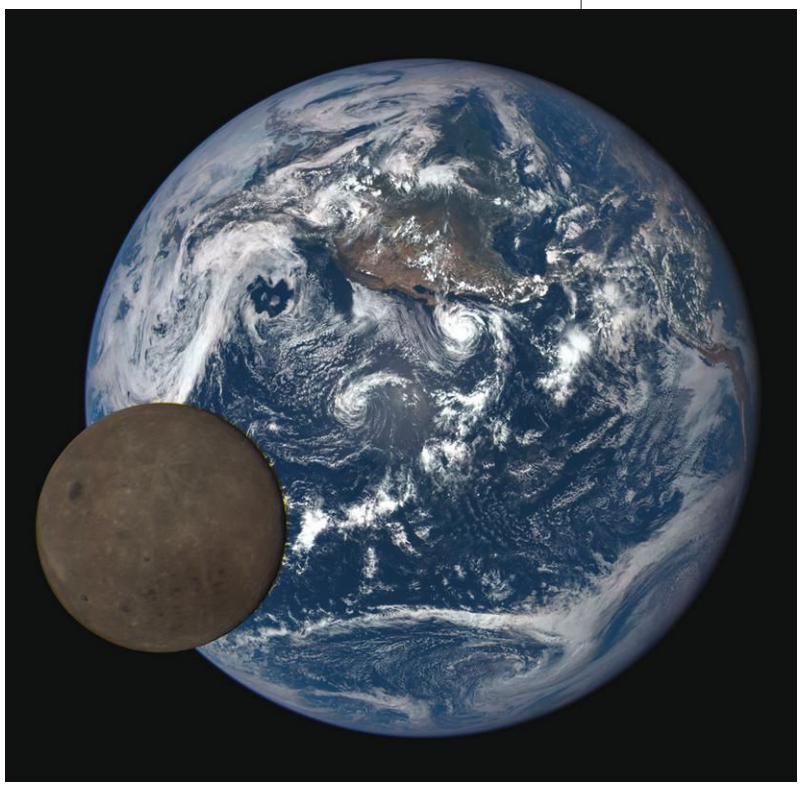
And we can figure this out for any planet! Good old Isaac Newton gave us an equation for figuring out the force of gravity almost 350 years ago. Gravity exists and works the same everywhere in the cosmos, but how strongly we feel it (i.e., its force) varies depending on how much mass is around.

The force of gravity between two objects, according to Newton, is equal to GMm/r^2, where G is the gravitational constant, a number that never changes. Newton figured this number out through lots of experimentation, which we've since refined in labs. Your mass (call it m), the amount of stuff you are made of, also doesn't change. (Well, it does if you win a hot-dog-eating contest, but not because of what planet you're on.) So that leaves us with M (the mass of the planet) and r (its radius, assuming you're standing on its surface).

NASA provides us with a list of planets' masses and radii — you'll find it at https://nssdc.gsfc.nasa.gov/planetary/factsheet/ — and then you just need a calculator to figure out the rest!

By the way, we use kilograms and pounds interchangeably on Earth, because no matter what country you're in, Earth's gravity doesn't change. But that doesn't work once you leave the ground. Out in space, a kilogram is still a kilogram, because it's a measure of *mass* — how much stuff you're made of. But a pound is actually a measure of *force* — how hard the planet's gravity is tugging. So if you're planet-hopping, you really want to compare pounds and Newtons (the latter of which is in units of kilograms x meters/second^2).

Korey Haynes
Associate Editor



The Deep Space Climate Observatory (DSCOVR) captured this image of the Moon and Earth in July 2015. Due to its smaller mass — and therefore, lower gravitational pull — you would weigh less on the Moon than Earth. NASA/NOAA

The field stop is the visible ring that sits in front of an eyepiece's field lens. It, along with the focal length of the telescope you're using, will determine the amount of sky you can see.
ALISON KLESMAN

Q | WHAT IS THE BENEFIT OF A 2" EYEPIECE COMPARED TO A 1¼" EYEPIECE?

Tom Nagy
North Ridgeville, Ohio

A | A 2" eyepiece delivers a wider true field of view (the actual amount of sky visible) than a 1¼" eyepiece of the same focal length. Two factors determine the true field: the telescope's focal length and the diameter of the eyepiece's field stop. A field stop is a centered, circular opening in front of the eyepiece's front (or field) lens. The bigger the field stop, the more sky you'll see.

The only limit to field-stop size is the inside diameter of the eyepiece's barrel. So, for example, a 20mm 2" eyepiece will show more sky than a 20mm 1¼" eyepiece through the same telescope. What's more, the magnification through both eyepieces will be the same.

Most observers prefer a wider field that doesn't sacrifice higher magnification. This really helps skywatchers whose telescopes lack a motorized drive. A wider true field of view means you have to manually move your scope less often to follow objects as Earth rotates.

Michael E. Bakich
Associate Editor

Q | COULD THE NEARBY STAR SIRIUS B EXPLODE AS A TYPE IA SUPERNOVA, LIKE SOME OTHER WHITE DWARF STARS IN BINARY STAR SYSTEMS HAVE?

Bruce Mason
Encinitas, California

A | A type Ia supernova occurs when a white dwarf — the cooling remnant of an aging star — draws hydrogen from a companion sun. When the dwarf reaches 1.4 times the mass of the Sun, the star spontaneously detonates in a fantastically bright thermonuclear blast. Nothing remains of the dwarf except debris.

The Sirius system, about 8.6 light-years from us, does include a white dwarf star (Sirius B) orbiting a companion (Sirius A). However, Sirius B is not close enough to its companion to accrete hydrogen and

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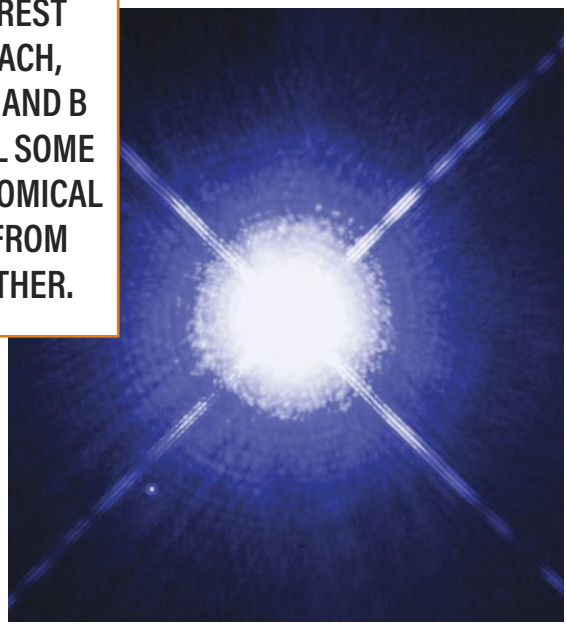
reach the supernova threshold of 1.4 solar masses.

Sirius B takes roughly 50 years to orbit Sirius A. At their nearest approach, the stars are still some 7 astronomical units (AU) from each other, or seven times the Earth-Sun distance. (One AU is equal to the average Earth-Sun distance of 93 million miles [150 million km].) The separation is too wide for mass to cross between Sirius A and Sirius B.

For mass transfer to occur, the two stars would need to be within a few stellar radii of each other. At that distance, they would complete an orbit over a period of hours to days.

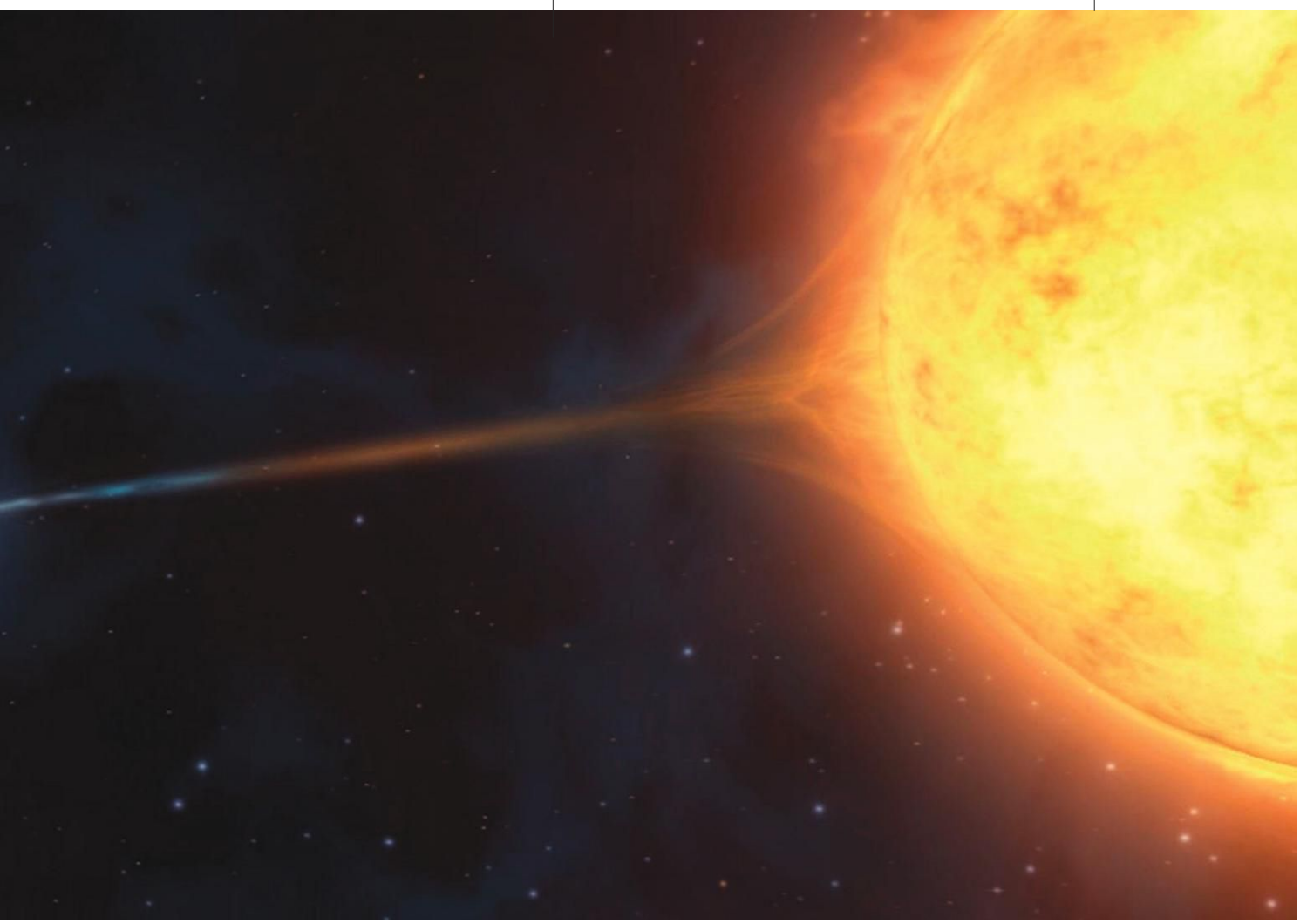
Liz Kruesi
Freelance Science Writer and Editor, Denver, Colorado

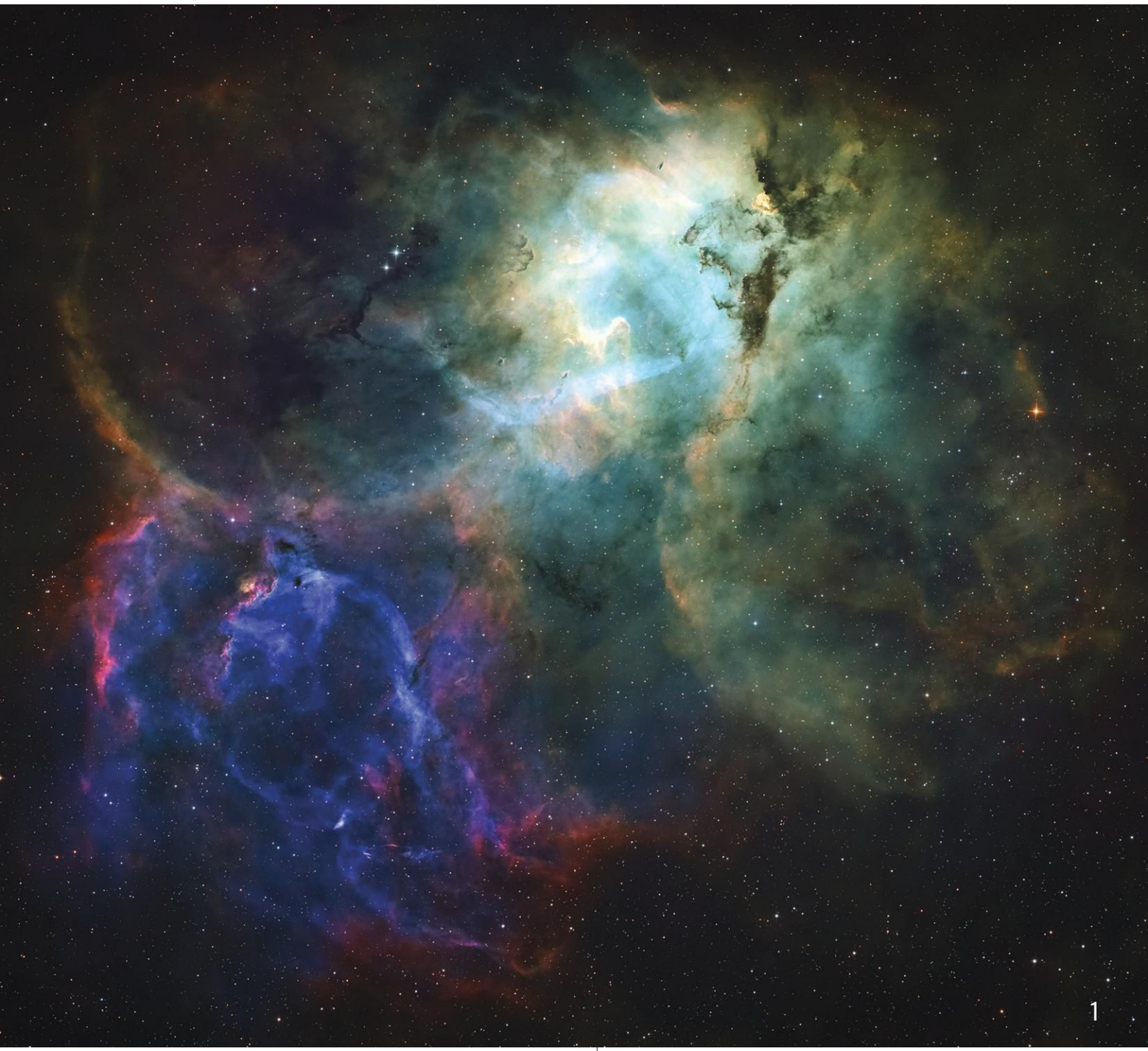
AT NEAREST APPROACH, SIRIUS A AND B ARE STILL SOME 7 ASTRONOMICAL UNITS FROM EACH OTHER.



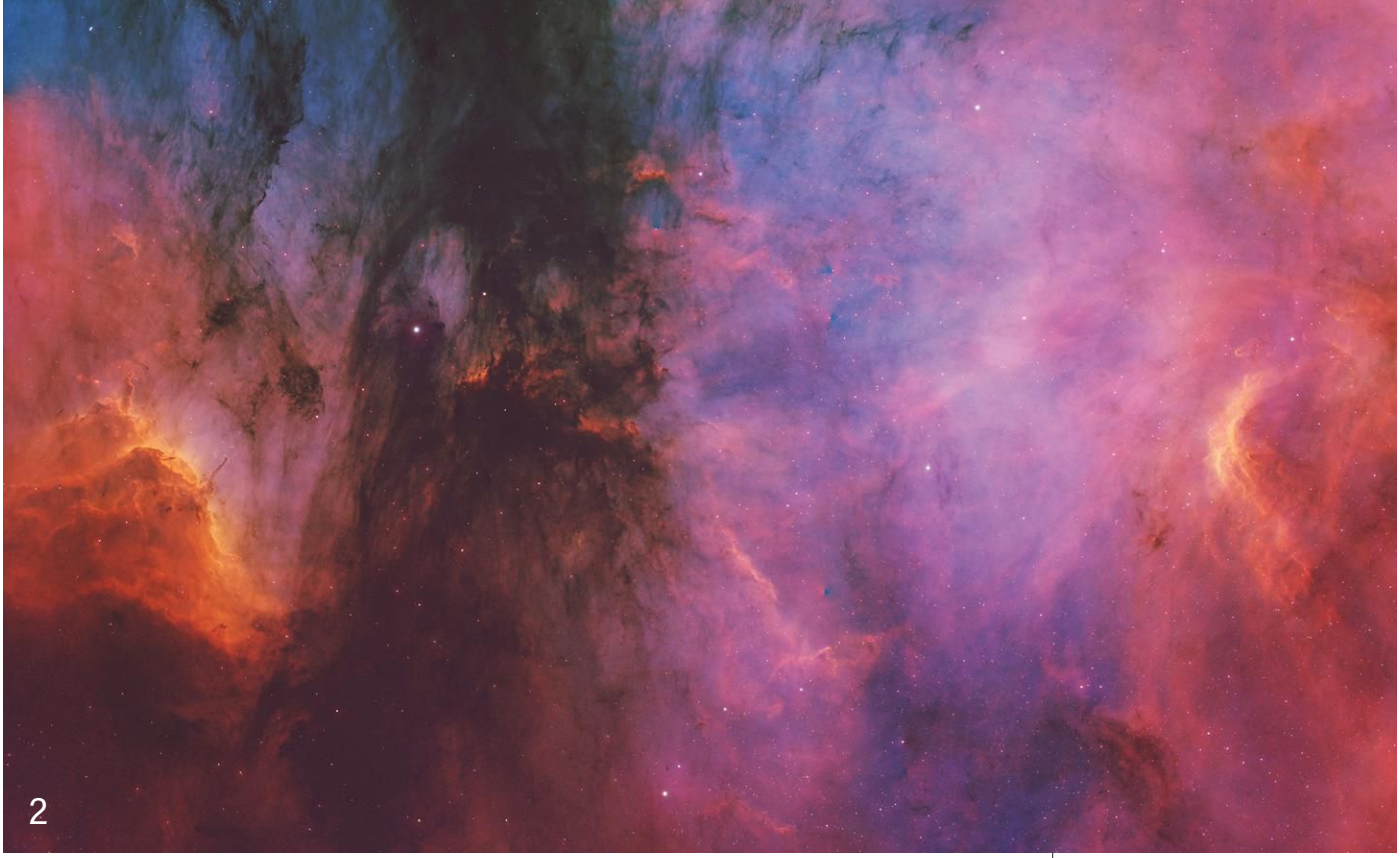
LEFT: Blazingly bright Sirius A dominates this Hubble Space Telescope image. Its smaller white dwarf companion, Sirius B, is the small dot at lower left. NASA, ESA, H. BOND (STSCI), AND M. BARSTOW (UNIVERSITY OF LEICESTER)

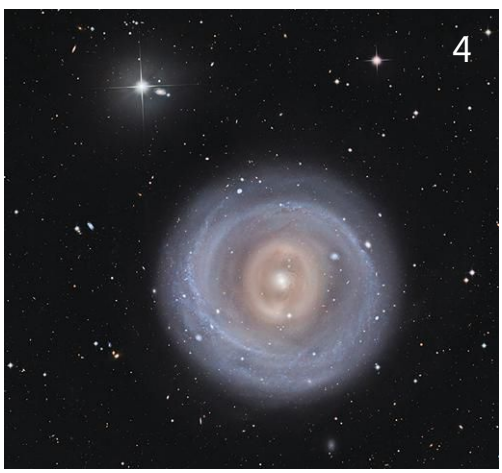
BELOW: This artist's impression shows a binary system in which a white dwarf (left) is pulling mass off its stellar companion. Such a system is the precursor for a type Ia supernova; however, the stars of the Sirius system are too widely separated for mass transfer to occur. ESO/M. KORNMESSER





1. THE LION'S MARKINGS
The Lion Nebula (Sharpless 2-132) is a faint emission nebula lit by young hot stars. Their winds and radiation are expanding outward, forming shock waves that comprise many of the lion's features. This shot also accentuates the remarkable play of light and shadow around the lion's "head." The imager took 46 hours of data in Hubble-palette filters with a 6-inch f/4 scope. ***• David Gluchowski***



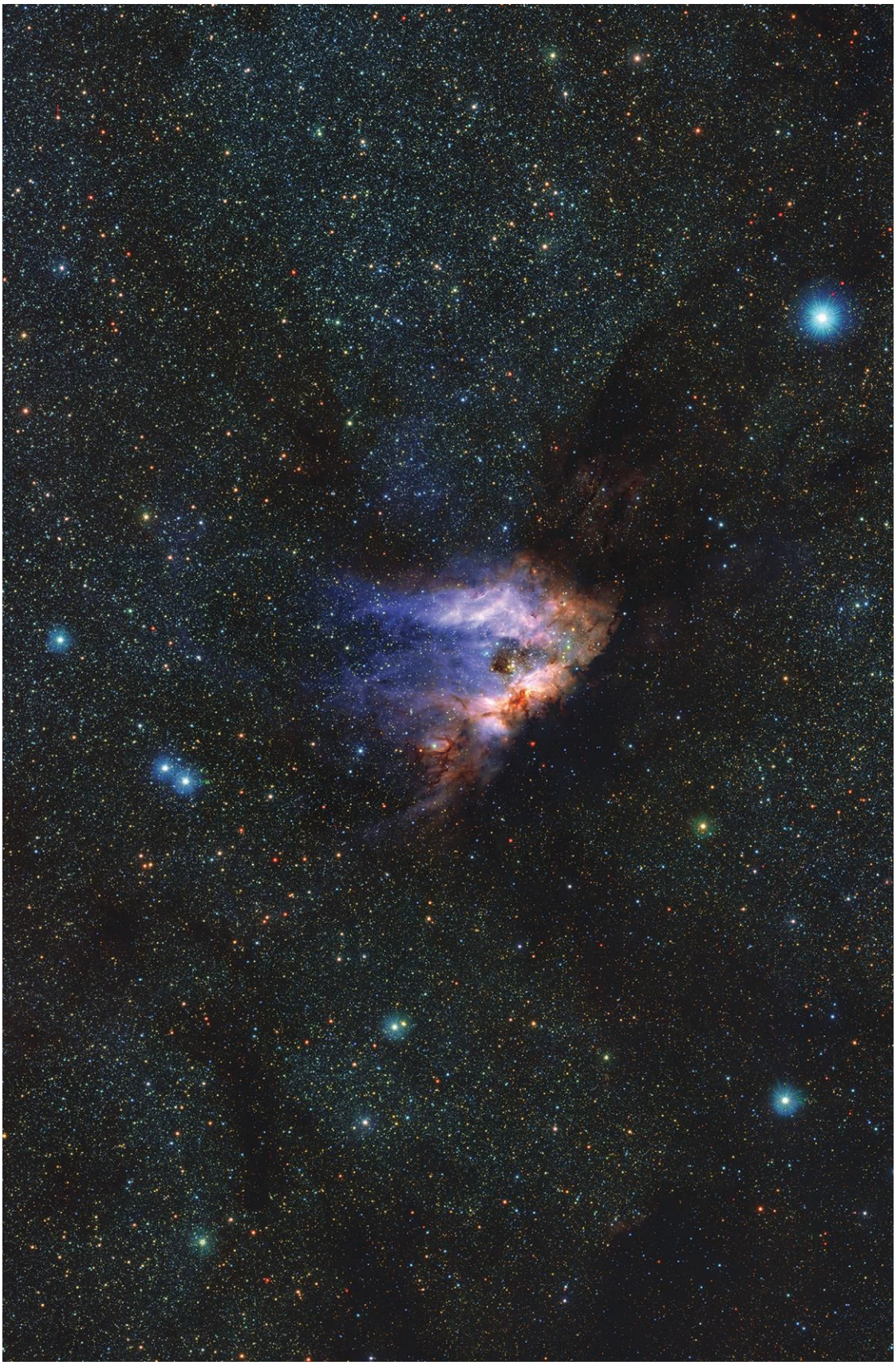


2. THE BILLOWING COSMOS
The dark nebulae LDN 935/6 contrast with surging clouds of bright emission from the North America Nebula (NGC 7000). For this close-up study of light and dark in motion, the imager took 13¼ hours of exposure in the Hubble palette with a 5-inch scope. ***• Jeff Schilling***

3. ERUPTING AT THE MOON
A Last Quarter Moon lies above an active Mount Etna on the island of Sicily in this early-morning shot from July 28, 2024. The imager used a Nikon Z 6II mirrorless camera and 150mm lens, taking a two-second exposure at f/8 and ISO 2000. ***• Massimo Tamajo***

4. RING OF FIRE
At 12 billion years old, the galaxy NGC 1291 in Eridanus has lost most of its spiral structure and matured into a transitional state — yet it has an outer ring that is still forming stars. The imager used a remotely operated 24-inch scope to take LRGB exposures of 7 hours 21 minutes, 1.5 hours, 1.5 hours, and 1.5 hours, respectively. ***• Vikas Chander***

5. DUST ON DUST
The origin of the reflection nebula vdB 9 in Cassiopeia is the Cepheid variable star SU Cas; its blue light is reflected by surrounding dust, which is itself partially shrouded by thicker dust clouds. This image represents five hours of exposure with an 8-inch scope in RGB filters. ***• Lynn Hilborn***



EXPOSING A NEW VISTA

You could forgive M17 for having an identity crisis. Observers refer to this emission region as the Omega, the Swan, and even the Checkmark Nebula. M17 doesn't even know what constellation to call home — most of it lies in Sagittarius, but its northern edge crosses into Serpens. Yet no one can deny the stellar nursery's good looks. This infrared view penetrates much of the dust that obscures the budding star cluster emerging within M17. Astronomers captured the Swan, which resides 5,500 light-years from Earth, with the 4.1-meter Visible and Infrared Telescope for Astronomy (VISTA) located on Cerro Paranal in Chile. The image is just a tiny piece of a giant infrared map covering an area equal to 8,600 Full Moons. The survey took 13 years to complete and captured more than 1.5 billion objects. ESO/VVVX SURVEY

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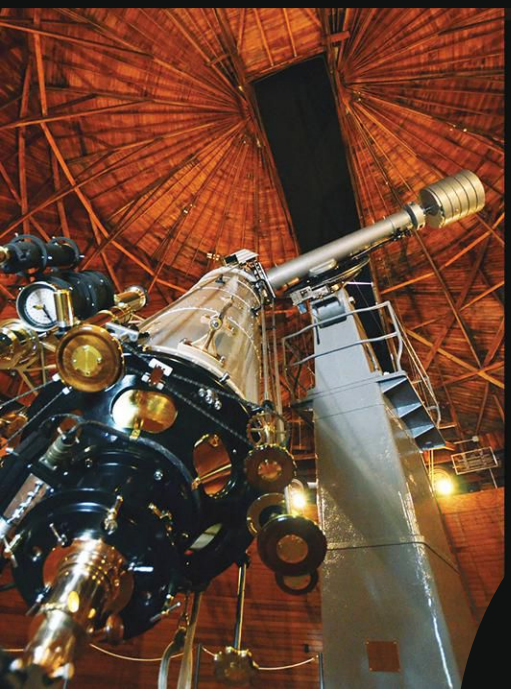

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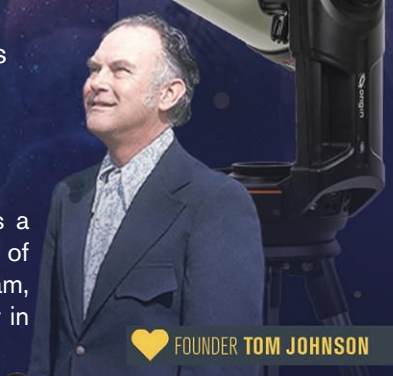

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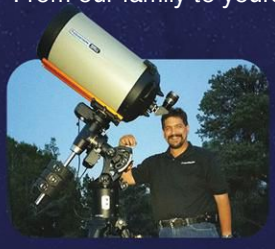

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May 2025
A Beehive of activity

As twilight fades to night these May evenings, **Mars** stands out in the northern sky. It begins the month near the center of Cancer the Crab not far from the magnificent Beehive star cluster (M44). The planet passes less than 1° north of the cluster during May's first week. Mars' eastward motion carries it into Leo the Lion on May 26, and it ends the month slightly to the left of Leo's famous Sickle asterism.

The Red Planet fades a bit during May, dipping from magnitude 0.9 to 1.2, but it remains prominent in part because of its striking color. Mars no longer appears great through a telescope, however, because its disk has slimmed to just 6" in apparent diameter. Wait for moments of good seeing to view any details.

Jupiter shines at magnitude –1.9 in mid-May. It gleams 16 times brighter than Mars and appears conspicuous in the northwest after nightfall in early May. The giant planet sets during twilight as the month winds down, however. Jupiter lies among the background stars of eastern Taurus, passing 1° north of the Crab Nebula (M1) at midmonth.

A telescope reveals the gas giant's 33"-diameter disk and two dark belts, one on either side of a brighter zone that coincides with the planet's equator. Jupiter's four bright moons — Io, Europa, Ganymede, and Callisto — also show up in the smallest of instruments.

Mars sets before midnight local time, leaving the sky free of naked-eye planets for several hours. The drought ends by 4 A.M. local time when Venus and Saturn clear the eastern horizon. The two stand 4° apart at the start of May.

Venus shines at magnitude –4.7 and makes an unmistakable beacon in the predawn sky. The planet lies among the background stars of southern Pisces the Fish during most of May, though it manages to clip the corner of Cetus the Whale on the 12th. Venus ends the month near its greatest elongation from the Sun, which will take place June 1.

A telescope shows the planet's quickly changing size and phase. On May 1, Venus' disk spans 36" and appears 29 percent lit. At month's end, the planet measures 24" across and the Sun illuminates 49 percent of its Earth-facing hemisphere.

Saturn remains in Pisces all month, though it moves eastward more slowly than Venus and thus the two drift apart. By the 31st, nearly 25° separate the two planets. Saturn shines at magnitude 1.1, just 1 percent of Venus's luminosity though still far brighter than any of Pisces' stars.

With Saturn climbing higher in a dark sky every day, it puts on a great show through telescopes of all sizes. The rings remain backlit at the start of May, with Earth south of the ring plane and the Sun north of it. The Sun crosses to the south side on the 6th, returning the ringed planet to a more normal view that will last until we cross the ring plane again in October 2038. On May's final morning, Saturn measures 17" across while the rings span 38" and tilt 3° to our line of sight. Also keep an eye out for 8th-magnitude Titan, Saturn's brightest moon.

Our final planet graces the morning sky during the first three weeks of May. **Mercury** appears highest on the 1st, when it rises two hours before the Sun and lies about 15° below the Venus-Saturn pair. Mercury then shines at magnitude 0.1 and grows brighter as the days pass.

The best views through a telescope come early in the month, when the inner planet shows a slightly gibbous disk that spans 7". Mercury disappears during May's final week as it reaches superior conjunction on the 30th.

The starry sky

I've been presenting planetarium shows for decades now, and I always delight in projecting the current evening sky and pointing out the constellations. Sadly, most of the star patterns don't strongly resemble the object or creature they were named for, and some seem to have no connection at all.

So, what constellations are the easiest for beginning stargazers to identify with their namesakes? Let's start with those visible in our current evening sky.

Undoubtedly, Crux the Cross tops the list. The tiny constellation appears conspicuous now because it lies nearly overhead at midevening. Not far to Crux's lower left is another easy one: Triangulum Australe. Its three brightest stars form a nearly perfect isosceles triangle. The angular distance from Alpha (α), at the bottom in our current evening sky, to Beta (β) is 7.7°, while from Alpha to Gamma (γ) is 8.1°.

Swing around to the eastern sky and you'll find two more constellations you should have little trouble identifying. The dazzling stars of Scorpius the Scorpion make it a breeze to recognize. Corona Australis the Southern Crown proves a bit harder because its stars are not as bright. Look for it below the Scorpion's tail as the two climb through the eastern sky.

Once you see the Scorpion's shape, you might be surprised to learn that some observers see a different shape in its stars. Some Aboriginal people of northern Australia think it resembles a crocodile.

Dare I add another? Chamaeleon the Chameleon may be on the obscure side, but it definitely looks like an animal to me — though admittedly it's upside down on May evenings. Look for it about 20° below Crux. You'll need a dark sky to spot this constellation's faint stars.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. May 1
8 P.M. May 15
7 P.M. May 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

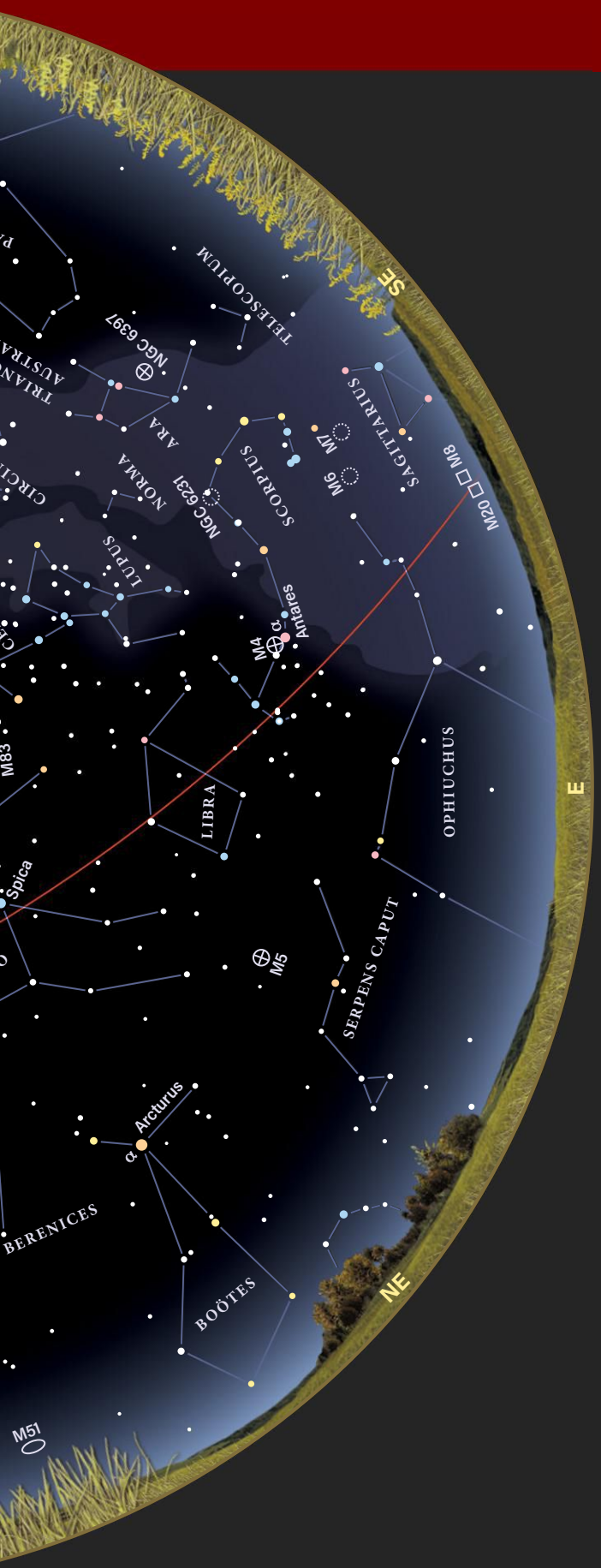
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



MAY 2025

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

2 Asteroid Vesta is at opposition, 6h UT

3 The Moon passes 2° north of Mars, 23h UT

4 Venus passes 2° north of Neptune, 3h UT

First Quarter Moon occurs at 13h52m UT

6 Eta Aquariid meteor shower peaks

Pluto is stationary, 6h UT

9 Asteroid Metis is at opposition, 6h UT

10 The Moon passes 0.4° south of Spica, 8h UT

11 The Moon is at apogee (406,244 kilometers from Earth), 0h47m UT

12 Full Moon occurs at 16h56m UT

14 The Moon passes 0.3° south of Antares, 5h UT

Asteroid Juno is at opposition, 18h UT

18 Uranus is in conjunction with the Sun, 0h UT

The Moon passes 0.4° south of Pluto, 12h UT

20 Last Quarter Moon occurs at 11h59m UT

22 The Moon passes 3° north of Saturn, 18h UT

The Moon passes 2° north of Neptune, 21h UT

24 The Moon passes 4° north of Venus, 0h UT

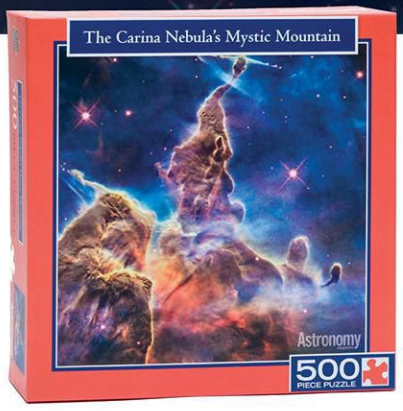
26 The Moon is at perigee (359,022 kilometers from Earth), 1h34m UT

27 New Moon occurs at 3h02m UT

28 The Moon passes 5° north of Jupiter, 13h UT

30 Mercury is in superior conjunction, 4h UT

EXPLORE THE UNIVERSE



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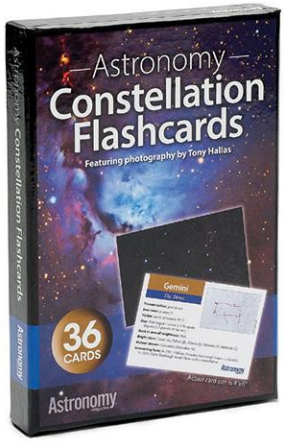

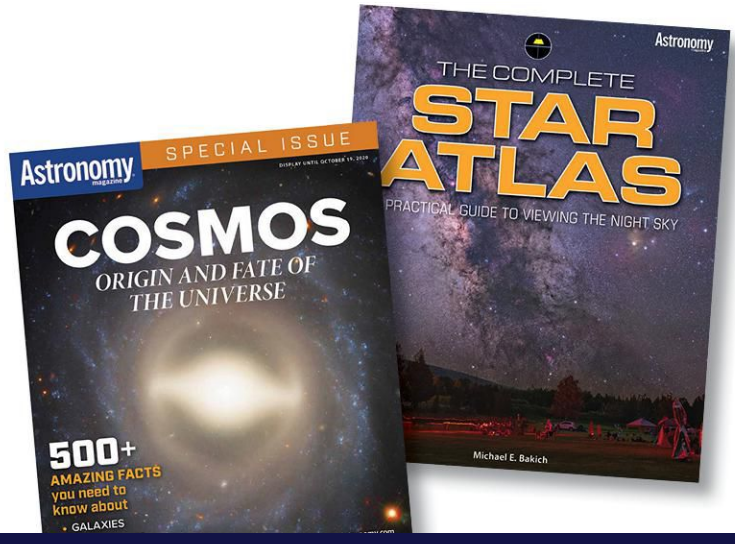

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